Giant Australian Cuttlefish (*Sepia apama*) Surveys 1998 – 2015

MA Steer, DJ Matthews and S Gaylard

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February 2016

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EXECUTIVE SUMMARY

Each winter, tens of thousands of Giant Australian Cuttlefish (*Sepia apama*) aggregate on a discrete area of rocky reef in northern Spencer Gulf, South Australia, to spawn. Given the iconic nature of this population there is a need to provide a robust assessment of its annual status to inform management and the general public.

Estimates of peak Giant Australian Cuttlefish abundance had indicated that the population declined to a record low of 13,492 individuals in 2013 before increasing 325% to 57,317 in the following season. The population continued to increase in 2015, peaking at 130,771 cuttlefish, representing a further 128% increase over the past year to provide the highest estimate since 2001. It was also the first time that the population had undergone two consecutive annual increases, indicating that like 2014, 2015 was also a favourable year for cuttlefish recruitment. This most recent population estimate represents 71.6% of the peak abundance of 182,585 animals observed in 1999.

Water temperature during the early life history stages of these two cohorts was >1°C warmer than the six-year average. Both laboratory and field studies have demonstrated that warming temperatures during the early life history phase accelerates growth and confers survival (Forsythe 1993). Although it is unlikely to be the only environmental factor shaping the Point Lowly Cuttlefish population, temperature appears to have had a strong influence in recent years.

There have been spatial and temporal changes in both habitat condition and water quality over the past three spawning seasons. However, these changes did not appear significant enough to negatively impact the aggregative behaviour of cuttlefish and spawning success.

Whyalla's Cuttlefish Citizen Scientist Group (WCCSG) collaborated with the South Australian Research and Development Institute (SARDI) to increase the temporal resolution of the 2015 survey. Although undertaken at different times, the estimates of Cuttlefish abundance at Black Point differed between the two groups by up to 67%, but there were no detectable differences in the under-water estimates of cuttlefish size. Accompanying volunteer divers with trained experts in future surveys would ensure greater scientific rigor in data collection.

Given the cuttlefish spawning area is likely to accommodate new coastal infrastructure associated with expanding resource-based industries in the near future it is important that the annual monitoring program continues to provide a greater understanding of the natural dynamics of the spawning population.

1. INTRODUCTION

1.1. Background

Each winter, tens of thousands of Giant Australian Cuttlefish (*Sepia apama*) aggregate on a discrete area of rocky reef in northern Spencer Gulf, South Australia, to spawn. The size of this population has been formally quantified since 1998 (Hall and Fowler 2003) and is the only known, dense aggregation of spawning cuttlefish in the world, and as such, the site has been identified as an area of national significance. A recent study that collated historic survey data, as well as undertaking a structured survey in 2012 indicated that the annual spawning aggregation had declined by ~90% over a 13-year period (Steer et al. 2013). The nature and extent of this decline raised significant concerns about the long-term viability of the population. This issue has continued to gain considerable national attention as it is widely recognised that northern Spencer Gulf is a prospering region for South Australian resource-based industries and its future development needs to consider the Gulf's unique biodiversity.

The 'cause' of the observed population decline is currently unknown, with a range of potential factors considered and investigated by Steer et al. (2013). One hypothesis relates to whether the current trend in the population reflects natural processes as cephalopod populations are renowned for their variable abundance (Pierce and Guerra 1994). The extent of the temporal data that exists for the Point Lowly Giant Australian Cuttlefish population is relatively short as there was no formal census or survey of the spawning aggregation prior to 1998. Therefore, it is not certain whether a peak in abundance recorded in 1999 was a result of a population increase (Hall and Fowler 2003), or whether it was indicative of a natural population size that has persisted through time. This paucity of information highlights the requirement for an on-going, annual monitoring program to provide a greater understanding of the natural dynamics of the population.

Given the iconic nature of the Point Lowly Giant Australian Cuttlefish population there is a need to provide a robust assessment of its status on an annual basis. Currently, a spatial closure for upper Spencer Gulf (north of Wallaroo) has been introduced as a precautionary measure to ensure that the cuttlefish population is not unnecessarily compromised by commercial and recreational fishing. Although, fishing has not been specifically identified to detrimentally affect the population it was the most amenable factor to control (Steer 2015). It is therefore important to assess the relative status of the Point Lowly Giant Australian Cuttlefish population to inform fishery management and assist in the development of the most appropriate strategies.

The relatively isolated stretch of rocky reef that fringes Point Lowly is considered an essential feature in attracting the large numbers of spawning Giant Australian Cuttlefish to the area as it provides substrate upon which they can attach their eggs and seek shelter. The proximity of this area to coastal urbanisation and industrial activity presents potential issues with respect to water quality and eutrophication that may influence local productivity. As such, the historic Giant Australian Cuttlefish monitoring program was recently expanded to include an assessment of the relative condition of the spawning environment through routine characterisation of the habitat and analysis of the ambient water quality (Steer et al. 2013). Given the strong association between spawning cuttlefish and the local substrate it was considered important to understand the impact of any shifts or large-scale changes in habitat condition or ambient water quality on spawning success.

1.2. Objectives

This study aimed to use the standard survey methodology that was described in Steer et al. (2013) to: estimate Giant Australian Cuttlefish abundance and biomass of the Point Lowly spawning aggregation; characterise the spawning habitat; and analyse the ambient water quality for the 2015 spawning season. Furthermore, this study incorporated survey data collected by a citizen scientist group to improve our understanding of the fine-scale variation in Giant Australian Cuttlefish abundance at a key spawning site.

2. METHODS

2.1. Standard Survey

The methods have been extensively described in Steer et al. (2013). In summary, the survey used replicated 50 x 2 m belt-transects to determine the relative density and size of Giant Australian Cuttlefish across ten sites that extend from False Bay to Fitzgerald Bay (Figure 2.1) in late-May, mid-June and early-July. An extra site, ‘Backy Point’, was included in the analysis to inform about the activity of Giant Australian Cuttlefish outside of the main spawning area, however, these data were not considered in the overall estimate of abundance and biomass. Mean estimates of Giant Australian Cuttlefish density and weight (kg per m^2) were calculated for each site and multiplied by the corresponding area of spawning substrate to provide an overall estimate of Giant Australian Cuttlefish abundance and biomass.

The habitat characteristics were determined from replicated underwater photo-quadrats taken along each of the belt-transects. From these digital images the percentage cover of the various algal functional groups that dominate the benthic habitat were quantified using image analysis software. Replicated water samples were collected from each site and the concentrations of inorganic (total ammonia) and total (nitrogen and phosphorus) nutrients, and chlorophyll *a* were analysed. A series of temperature loggers were deployed in northern Spencer Gulf (Plank Shoal, Western Shoal and Ward Spit) in October 2005 as part of an unrelated project (see Saunders 2009). Additional loggers were deployed at Black Point and SANTOS Tanks in July 2012 and were set to record hourly water temperature. The time series of temperature data presented in this study has been extracted from two spatially separate (~20 km) data loggers (i.e. Plank Shoal (June 2009 – July 2012) and Black Point July 2012 onwards). The data were aggregated and presented as averages (daily and weekly) to provide a composite trend of the seasonal variation in temperature within the northern Gulf. Trends in water temperature from June 2009 onwards were investigated in relation to the key developmental periods (i.e. embryo development period and early life history) of Giant Australian Cuttlefish on the spawning ground.

Spatio-temporal differences in habitat and water chemistry were assessed by permutation multivariate analysis of variance (PERMANOVA) and principal component analysis (PCA). Prior to analysis, data were log transformed and normalised and a resemblance matrix was developed using the Euclidian similarity distances. PERMANOVA was undertaken using unrestricted permutation of the data using 9999 permutations. All statistics were undertaken using the PRIMER v6.1 (Clarke and Gorley 2006) and PERMANOVA+ add on (Anderson et al, 2008).

2.2. Citizen Scientist Survey

Whyalla's Cuttlefish Citizen Scientist Group (WCCSG), which consists of 17 local divers, undertook a series of *ad hoc* surveys throughout the spawning season to complement SARDI's formal monitoring program. They adhered to the standard survey methodology, but concentrated on assessing the temporal variation in the population at a key spawning site (Black Point) and did not assess habitat condition, nor collect water samples. Although this group received some guidance and advice from SARDI prior to the start of the 2015 cuttlefish breeding season; their field operation, data collection and collation was independent of the formal monitoring program.

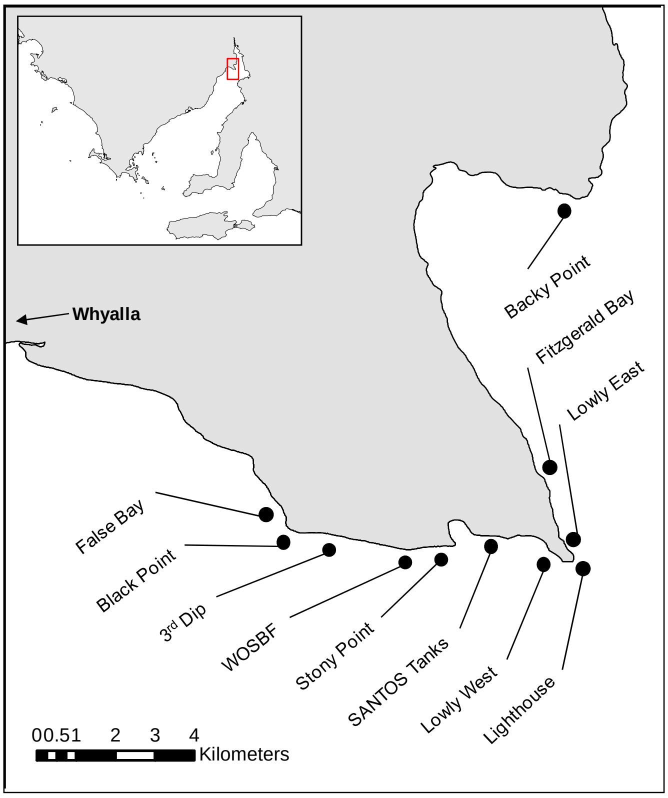

Figure 2.1. Location of survey sites fringing Point Lowly in Northern Spencer Gulf.

3. RESULTS

3.1. Giant Australian Cuttlefish Abundance and Biomass

The 4 km stretch of reef extending from False Bay to Stony Point constitutes the main Giant Australian Cuttlefish spawning area (Figure 3.1). Peak cuttlefish density sequentially increased at each of the key spawning sites west of the Point Lowly Lighthouse over the past three years. This was most evident west of the Santos Boundary Fence (WOSBF) and Stony Point, where cuttlefish densities increased up to 0.4 cuttlefish/m^2 in 2015. Furthermore, the relatively high density of spawning cuttlefish at these two sites endured throughout the three month survey. This pattern contrasts with the sites further west (False Bay, Black Point and 3rd Dip) where densities peaked either in May or June and declined considerably by July. Unlike previous years, cuttlefish densities at the Point Lowly Lighthouse site were higher in 2015, remaining above 0.09 cuttlefish/m^2 throughout the survey period. Despite a marked increase in the overall density of Giant Australian Cuttlefish abundance across the key spawning area in 2015, some sites continued to support low numbers. These sites included Santos Tanks, Point Lowly West, Point Lowly East and Fitzgerald Bay, where densities declined from 0.03 to 0 cuttlefish/m^2, respectively. Backy Point, which is located approximately 8 km north of the Point Lowly Peninsula, has consistently supported low numbers (<0.04 cuttlefish/m^2) of spawning cuttlefish, peaking at 0.03 cuttlefish/m^2 in June 2015.

The overall estimates of Giant Australian Cuttlefish abundance of the spawning population in 2015 peaked in June at 130,771 individuals, which was 41% more than the May estimate and subsequently declined by 47% to 69,466 in July (Figure 3.2). This level of variation for the three month survey contrasted with results from 2013 and 2014 when the size of the spawning aggregation remained comparably stable through-out the peak spawning period.

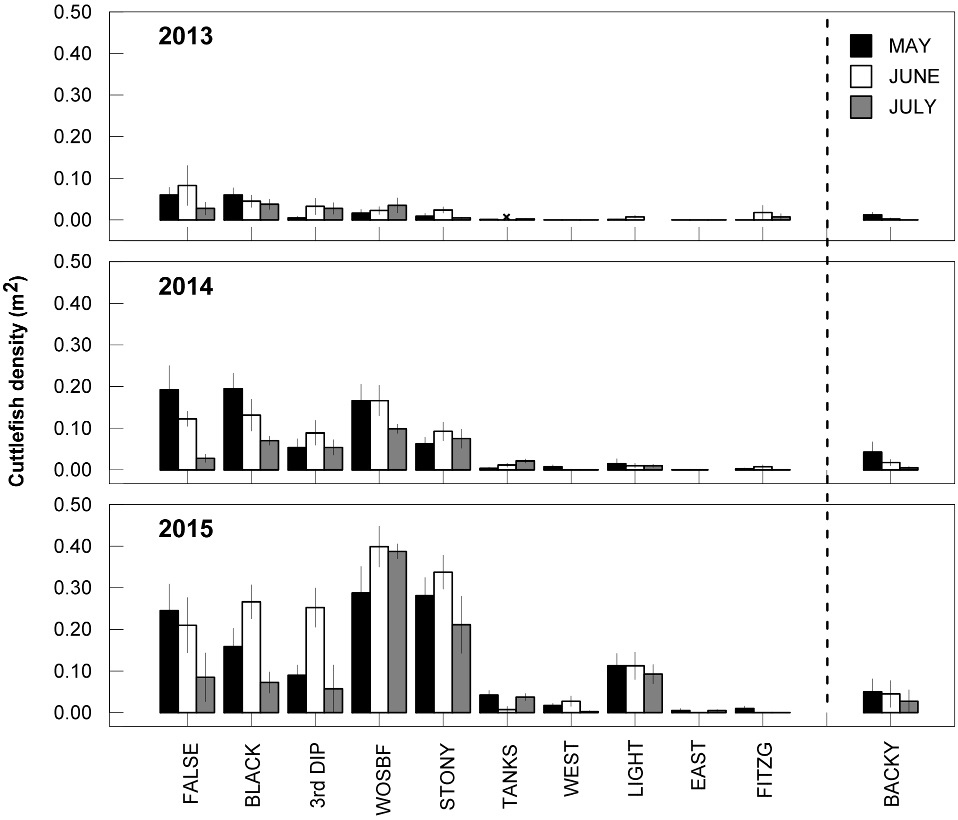

Figure 3.1. Monthly mean Giant Australian Cuttlefish density (± se) across each survey site for the 2013 (top), 2014 (middle) and 2105 (bottom) surveys. Note, data presented for Backy Point have not been included in the overall estimates of abundance.

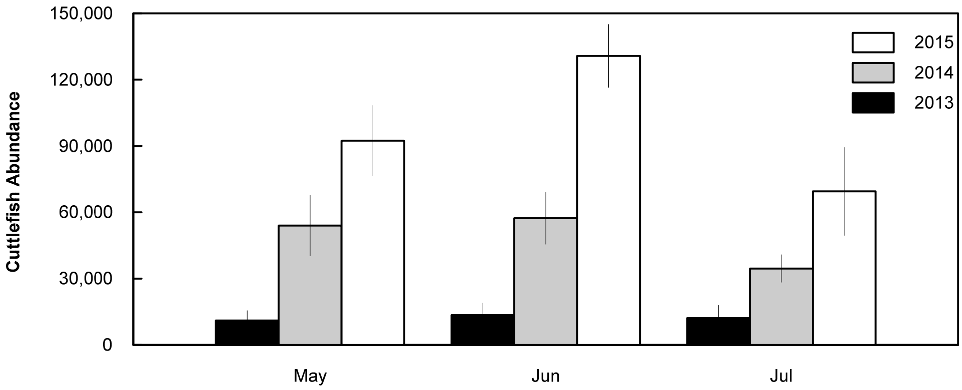

Figure 3.2. Extrapolated estimates of total Giant Australian Cuttlefish abundance (± se) for each month of the 2013, 2014 and 2015 surveys.

Estimates of peak Giant Australian Cuttlefish abundance had indicated that the population declined to a record low of 13,492 individuals in 2013 before increasing 325% to 57,317 in the following season. The population was higher again in 2015, peaking at 130,771 cuttlefish. This represents a further 128% increase over the past year to provide the highest estimate since 2001 (Figure 3.3). It was also the first time that the population had increased over two consecutive years, indicating that like 2014, 2015 was also a favourable year for cuttlefish recruitment. The 2015 population estimate represented 71.6% of the peak abundance of 182,585 observed in 1999.

The estimated biomass of cuttlefish conformed to a similar long-term trend to abundance. The decline was most pronounced in 2013 dropping to 6.8 t, representing a 96.8% reduction from the historic peak of 211.1 t in 1999 (Figure 3.3). This recovered to a biomass of 88.1 t in 2015. The decline in biomass, particularly from 2011 to 2013, was influenced by a truncation in the size composition of the spawning population (Figure 3.4). The average size of both males and females during these three years was considerably smaller compared with other years. The 589% increase in biomass to 47.1 t in 2014 was bolstered by a return of relatively large animals. Despite the further increase in abundance in 2015, the spawning population was, once again, comprised of below-average sized animals, with males and females measuring 189 mm and 158 mm, respectively. Although considerable, the annual increase in biomass in 2015 to 88.1 t (87.1%) was tempered by comparatively small cuttlefish, representing less than half (41.7%) of the 1999 peak (Figure 3.3).

Males typically dominate the spawning population by approximately 4:1. The composition of the 2015 spawning population, was further biased towards males, as females only accounted for 17% of the encountered animals, representing a male-dominated sex ratio of approximately 6:1. The relative proportion of encountered females was the lowest on record, 6.5% less than the long-term population average (Figure 3.4).

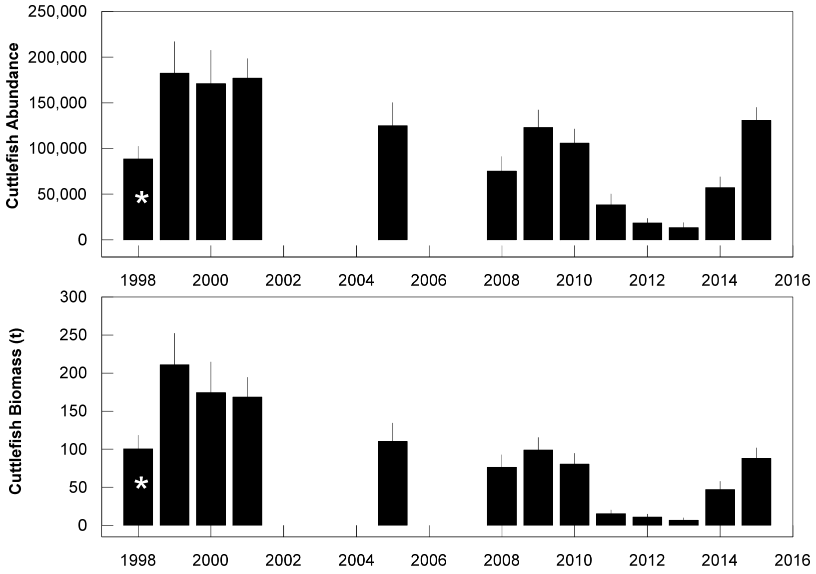

Figure 3.3. Annual estimates of total abundance and biomass (± SD) of Giant Australian Cuttlefish aggregating around Point Lowly during peak spawning from 1998 to 2015. * Population was heavily fished. Historic data obtained from Hall and Fowler (2003).

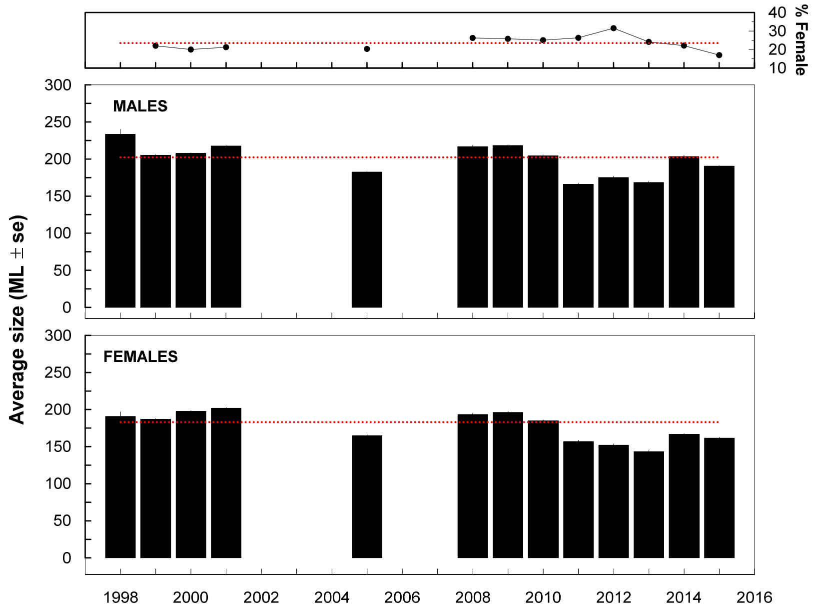

Figure 3.4. The population sex ratio presented as the percentage of females (top). The average size of Giant Australian Cuttlefish (± se) for males (middle) and females (bottom) from 1998 to 2015. The red lines represent the overall average.

3.2. Habitat Characterisation

Four algal functional groups: highly branched robust algae (BRBRANCH); brown foliaceous algae (BRFOLI); red foliaceous algae (RFOLI); and *Hincksia* sp. (HINCK), were the most prominent along the Point Lowly Peninsula fringing reef, collectively accounting for >50% of the algal habitat. Their relative coverage, however, varied between sites over the past three survey years (year*site interaction: Psuedo-$F_{18,81}$ = 1.82, p = 0.014). All sites along the western end of the Point Lowly Peninsula, with the exception of False Bay (Black Point, 3rd Dip, WOSBF and Stony Point) exhibited proportionately higher coverage of BRFOLI in 2015 compared with the previous two years (Figure 3.5). Conversely, the eastern end of the Peninsula (Tanks, Pt. Lowly East) exhibited extensive stands of BRBRANCH in 2015, exceeding 60% of the relative cover, approximately 30 to 50% greater than observed in previous years (Figure 3.6). The annual coverage of RFOLI has remained relatively consistent at each site, with the exception of Pt. Lowly West and the Lighthouse where it varied by approximately 20%. *Hincksia* sp. was most predominant and widespread in 2013, particularly on the eastern and western sides of Pt. Lowly with relative coverage exceeding 15% (Figure 3.6). These two sites continued to support low levels (<15%) of HINCK in 2014, but it was largely absent in the broader area. The relative cover of HINCK in 2015 was negligible, rarely exceeding 5% coverage (Figure 3.6).

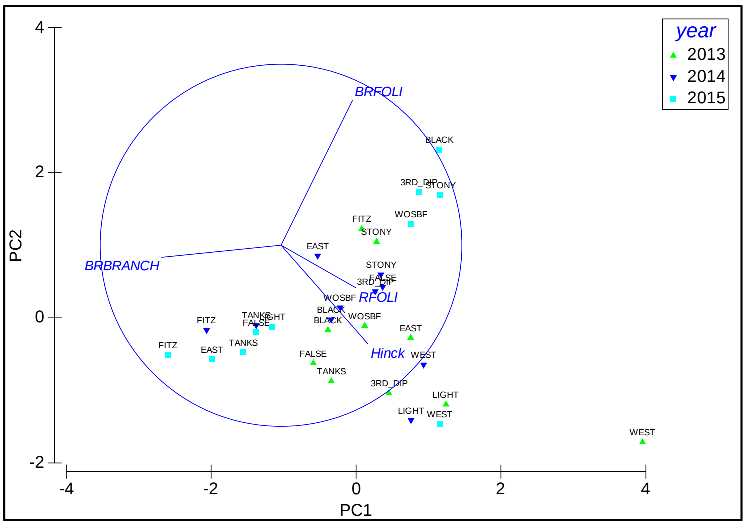

Figure 3.5. Principal component analysis of the four main algal groups for each of the sites spanning the Point Lowly Peninsula over the past three survey years (2013, 2014 and 2015).

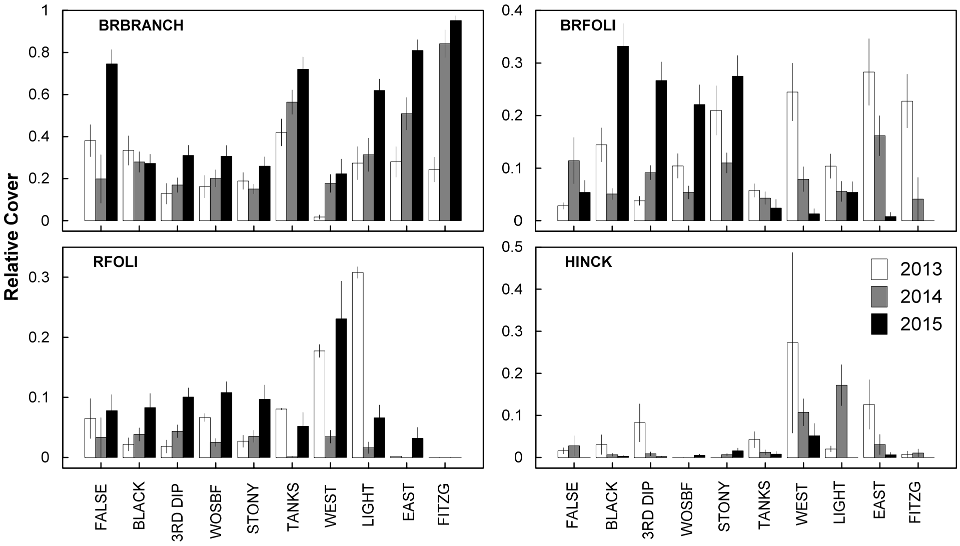

Figure 3.6. The average relative cover (± se) of the four main algal groups for each of the sites spanning the Point Lowly Peninsula over the past three survey years (2013, 2014 and 2015).

3.3. Ambient Water Quality

There was generally little variation in ambient water quality between sites during each sampling occasion, indicating that shallow water chemistry throughout the Point Lowly area was relatively homogeneous. There was, however, some variation between sites in June 2013 when sampling coincided with a period of very low water movement and mixing (dodge tide). Overall, the water chemistry profile was temporally unstable as it differed across each month (site*month(year) interaction: Psuedo-$F_{36,140} = 1.88$, $p < 0.001$). Total nitrogen was a strong influencing component in most sampling events with much of the data clustered around this vector (Figure 3.7). The dodge tide event (6_2013) resulted in a greater concentration of dissolved inorganic nitrogen (DIN) being detected, particularly at 3rd Dip, Stony Point and Point Lowly West (Figure 3.7). The chemical profile of the shallow water during July 2015 was charactersied by a relatively high average concentration of filtered reactive phosphorous, that exhibited a broad regional profile that was markedly different to the previous sampling occasions (Figure 3.7). While not tested statistically there was a broad negative association with month progressing through the year with decreasing concentrations of total nitrogen (except July 2014), filtered reactive phosphorus and chlorophyll a (except June 2014) (Figure 3.8).

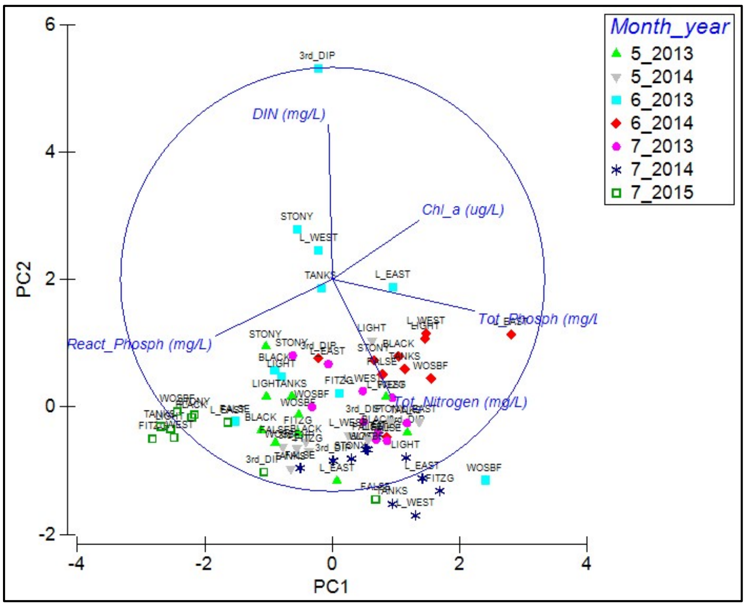

Figure 3.7. Principal Components Analysis of monthly water quality parameters (Total nitrogen, total phosphorus, dissolved inorganic nitrogen (DIN), filtered reactive phosphorus and chlorophyll a) for each of the sites spanning the Point Lowly Peninsula over the past three survey years (2013, 2014 and 2015).

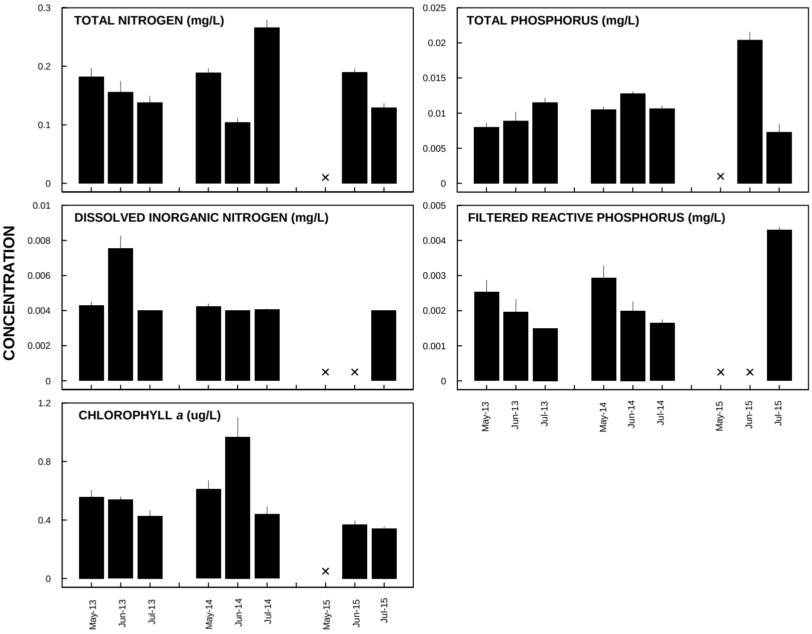

Figure 3.8. The average concentration (± se) of total nitrogen, total phosphorus, dissolved inorganic nitrogen, filtered phosphorus and chlorophyll *a* for the broader Point Lowly area over each survey occasion over the past three years (2013, 2014 and 2015). 'X' denote missing data due to analytical complications.

3.4. Temperature Profile

The daily average summer maximum of 26.8°C in 2013 was the highest recorded over the past six years (Figure 3.9). Similarly the preceding winter minimum in 2012 was moderately warm, exceeding 13°C for the first time since 2009. Peak spawning has typically occurred when winter temperatures dropped below 17.3°C and consequently the development of the resultant eggs and embryos occurred during the coldest time of the year. The duration of embryo development during this time is estimated to take approximately 120 days (Hall and Fowler 2003). The daily averaged temperature regime during this critical period varied considerably over the past six years. The 2013 cuttlefish cohort experienced the warmest conditions throughout the embryo development period, as its entire temperature profile during this time was above the six year average. This was particularly evident during the later stages of development (i.e. >70 days) when temperatures remained >1.2°C warmer than the overall average (Figure 3.10). Relatively high temperature pulses were also observed during this time, with embryos experiencing up to 1.3°C changes over weekly periods. Conversely, the 2010 cohort experienced an opposite temperature profile, initially remaining approximately 0.5°C above average before declining 2°C at the 100 day developmental milestone. This cohort experienced the coldest developmental temperatures so far. The 2014 cohort initially encountered below average temperatures (~1°C) for the first two months of development. This was not sustained as the temperature profile steadily increased over the subsequent weeks to peak at approximately 2°C above average towards the end of the developmental period.

A relatively strong positive relationship (r^2 = 0.77) was detected between the difference in the annual estimates of abundance and the average temperature anomaly calculated over the late embryo developmental period (i.e. from day 50 to 120) (Figure 3.11). This indicated that the population is likely to increase when the developing embryos experience relatively warm temperatures. Conversely, cooler temperatures during the early life stages will potentially lead to a decrease in the annual abundance of spawning cuttlefish along Point Lowly.

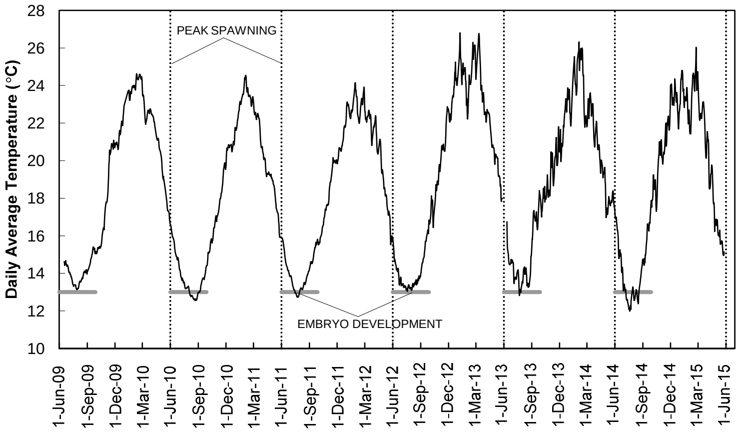

Figure 3.9. The daily average water temperature profile of Northern Spencer Gulf. Estimated periods of peak Giant Australian Cuttlefish spawning and 120 day embryo development are indicated.

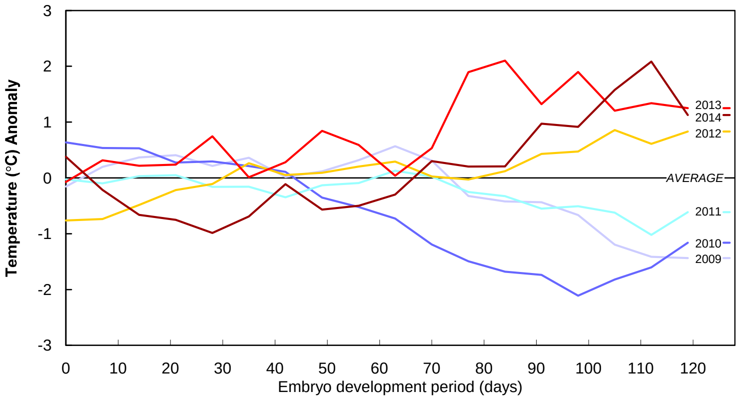

Figure 3.10. Weekly average temperature anomalies encountered by cuttlefish embryos developing over a 120 day period, compared against the 6 year average.

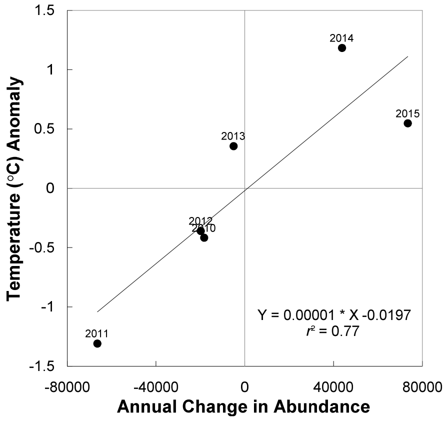

Figure 3.11. Relationship between average temperature anomaly encountered by developing cuttlefish embryos and the annual change in population abundance.

3.5. Citizen Scientists

Poor weather and the availability of volunteers often prevented the Citizen Scientist Group from undertaking surveys. Throughout the three-month peak spawning period this group coordinated four surveys at Black Point (shallow). Complete datasets, where the divers successfully recorded cuttlefish numbers encountered along four replicate belt-transects, were obtained from three of the four surveys. These surveys were carried out over the course of one week in early June 2015 (8th – 15th) and flanked the SARDI survey which occurred on the 10th June (Figure 3.12). The numbers of cuttlefish recorded by these two groups over this period were significantly different (*t*-test: *t* = -4.17, df = 14, p <0.001). Estimates of cuttlefish density by the Citizen Science Group were up to 67% lower than those obtained by SARDI (Figure 3.12). Similarly, estimates obtained over two consecutive days (8-9 June 2015) by the Citizen Science Group were statistically different (*t* = 2.98, df = 6, p = 0.02), where the second survey was 41% less than the first (Figure 3.12).

The overall estimate of the average size of Cuttlefish aggregating at Black Point was similar between the two groups (*t* = 0.41, df = 446, p = 0.68) (Figure 3.13).

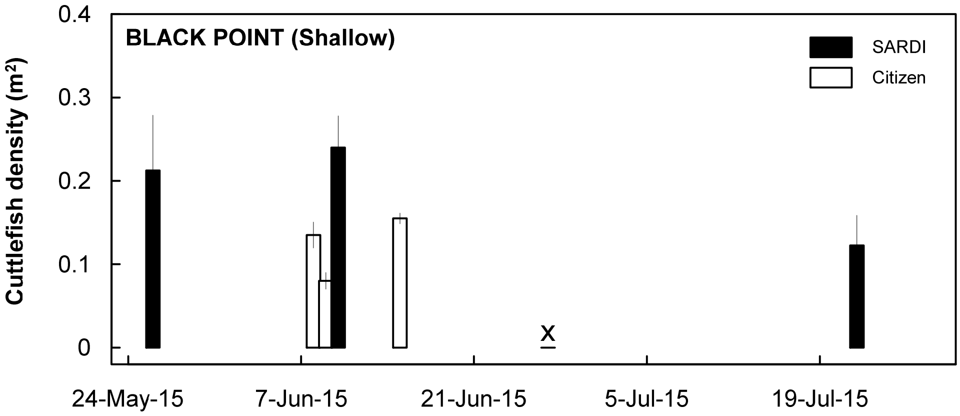

Figure 3.12. Comparison of average Giant Australian Cuttlefish densities (± se) aggregating at Black Point (Shallow) estimated by SARDI and Citizen Science Groups over the three month, peak spawning period. 'X' insufficient data.

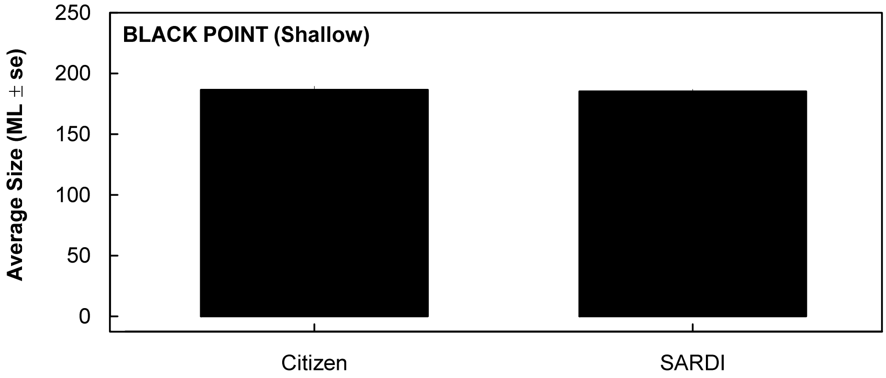

Figure 3.13. Comparison of the average size (± se) of Giant Australian Cuttlefish aggregating at Black Point (Shallow) estimated by SARDI and Citizen Science Groups over the three month, peak spawning period.

4. DISCUSSION

The Giant Australian Cuttlefish spawning population at Point Lowly has continued to increase in 2015, rising a further 128% from the 2014 estimate to approximately 131,000 animals. This consecutive increase from a record low of 13,492 individuals in 2013 indicates that both 2013/14 and 2014/15 were relatively favourable years for Giant Australian Cuttlefish growth and survival. Water temperature during the early life history stages of these two cohorts was >1°C warmer than the six-year average. It appeared that the temperature experienced by the developing embryos strongly influenced (accounted for 77% of the variation) the size of the resultant population. Warm years tended to increase the size of the spawning population, whereas cool years reduced it. Both laboratory and field studies have demonstrated that warming temperatures during the early life history phase accelerates growth and confers survival, provided that temperatures do not exceed the species thermal tolerance and food is not limited (Forsythe 1993). An increase of 1°C has been shown to increase the size of squid hatchlings by a factor of three at 90 days post hatching, highlighting their responsiveness to small changes in temperature (Forsythe 2004). Similar responses have been observed in captive-reared and wild-caught European Cuttlefish (*Sepia officinalis*) (Domingues et al. 2006). Although it is unlikely to be the only environmental factor shaping the Point Lowly Cuttlefish population, temperature appears to have had a strong influence in recent years.

There have been spatial and temporal changes in both habitat condition and water quality over the past three spawning seasons. There were notable changes in the relative cover of highly branched robust algae along the eastern end of the Pt Lowly Peninsula and increased coverage of brown foliaceous algae towards the western end in 2015. Despite these changes, these areas continued to support relatively high densities of spawning cuttlefish. The 'opportunistic' alga, *Hincksia* sp. has been suggested by local divers to prevent Giant Australian Cuttlefish from spawning in the area or interfere with embryo development through excessive fouling of the egg capsules (Steer et al. 2013). There were concerns that increased cover of *Hincksia* sp. at key spawning sites (i.e. Black Point, 3rd Dip and WOSBF) in May 2014 may have compromised spawning success and recruitment of the subsequent generation (Steer 2015). These concerns, however, appear unfounded as the population subsequently increased. The variation in ambient water quality also appeared to have a negligible effect on the spawning population and was more indicative of the broad-scale nutrient dynamics of Spencer Gulf (Gaylard et al. 2013; Middleton et al. 2013). These small changes in habitat condition and water quality are unlikely to have negatively impacted the aggregative behaviour of cuttlefish and spawning success. It is the potential effects of large-scale environmental changes, such as loss of natural habitat, increased nutrient loading and eutrophication that are of greater interest and affirms the need for on-going monitoring of the cuttlefish spawning habitat and ambient water quality. This is of particular importance as the area is likely to accommodate new coastal infrastructure associated with expanding resource-based industries in the near future.

Whyalla's Cuttlefish Citizen Scientist Group (WCCSG) collaborated with SARDI to increase the temporal resolution of the 2015 survey. The objective of this group was to survey a key spawning area (Black Point) between SARDI's formal surveys to resolve the fine-scale variation in cuttlefish population dynamics throughout the spawning season. Poor weather and lack of personnel, however, limited them to four surveys over a two-month period and from these, three complete datasets were provided. Prior to the surveys it was also acknowledged that this initial year would be treated as a 'trial case' to familiarise the group with the operational component of the survey with the potential to increase its level of contribution over subsequent spawning seasons. Although undertaken at different times, the estimates of cuttlefish abundance at Black Point differed between the WCCSG and SARDI by up to 67%, but there were no detectable differences in the under-water estimates of cuttlefish size. Identifying all cuttlefish within the 50 x 2 m belt transects can be challenging, especially finding those animals that are hidden deep within the complexity of the rocky reef or camouflaged amongst the branching algae. Such cryptic behaviour has previously presented difficulties for surveys undertaken using Remotely Operated Vehicles (Geo Oceans 2014) or towed video cameras (Steer et al. 2013). It is possible that the discrepancies in the counts between the two groups was related to survey experience, with some of the less experienced divers failing to detect cryptic cuttlefish. Alternatively, the estimates may accurately reflect a highly dynamic spawning aggregation. Comparing simultaneous surveys between the two groups would resolve this discrepancy. Accompanying volunteer divers with trained experts in future surveys would also ensure greater scientific rigor in data collection.

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