CHAPTER SIX

REPRODUCTIVE OUTPUT COMPARISONS OF PORT LINCOLN SILVER GULLS AND REFERENCE POPULATIONS

6.1 Introduction

Food availability is a limiting factor for reproduction in seabirds (Furness & Monaghan, 1987; Oro *et al*., 1999) as reproduction is energetically costly and if food is limited, it cannot occur effectively (Martin, 1987). Therefore, a source of abundant food enhances many aspects of reproduction including fecundity, egg composition, hatching success, chick survival and body condition, as well as decreasing mortality, increasing recruitment and in some cases lengthening the breeding season (Smith & Carlile, 1992; Smith, 1995; Oro, 1996; Oro *et al*., 1996; Annett & Pierotti, 1999). Reproductive output is also affected by other factors such as availability of adequate and safe nesting sites, breeding habitat, human disturbance, weather, timing of breeding and predation (Furness & Monaghan, 1987).

Fish are a high quality food source for seabirds and their availability is a crucial determinant of reproductive performance in many species (Annett & Pierotti, 1989; 1999; Bosch *et al*. 1994; Oro, 1996; Oro *et al*., 1996). In semi-precocial species like gulls, the quantity of yolk in the egg determines the developmental maturity of the young while the amount of albumen determines both egg and neonate size (Meathrel, 1991). Albumen is essentially water and protein, but yolk formation requires energy rich lipids and is thus more energetically demanding on laying females (Meathrel, 1991). Fish are high in both protein and lipid, and thus add to the quality of albumen and yolk, and are very important in egg formation for developing embryos (Meathrel, 1991; Wood, 1991; Oro, 1996). Post-hatch, fish are also a vital part of the diet for seabird chicks because they require a high level of digestible protein and calcium (Pierotti & Annett, 1987; Annett & Pierotti, 1989; Pierotti & Annett, 1990). Fish are also likely to be easier to swallow than most human refuse.

In areas where fish derived from human activity (e.g. fisheries discards) are not readily available, Western Gulls in California, have been shown to feed on human refuse until initiation of breeding, and then switch to foraging on fish (Annett & Pierotti, 1989; 1999). Similar seasonal facultative feeding on fish has been observed in several other species of gulls (Annett & Pierotti, 1989). Fish prey are a 'risk prone' but high quality food source as they usually require a short foraging period but there is high variance in trip time; compared to feeding on human refuse which may require a long foraging trip, but low variance in trip time as the source is more reliable, although lower quality (Pierotti & Annett, 1987; 1990; Annett & Pierotti, 1989). At its best, garbage when high in meat content is similar in fat, protein and caloric value to fish (Garbage: mainly meat – 19% fat, 13% protein, 1500kcal/kg (Pierotti & Annett, 1987); Baitfish – 3-13% fat, 13-20% protein, 717-1910kcal/kg (Ellis & Rough, 2005)). However, garbage also contains low protein, high carbohydrate items such as bread, rice, pasta, pizza, chips etc. Whilst it can sustain reproduction in gulls, unlike fish, it is deficient in calcium and sulphonated amino acids which are extremely important for egg formation and bone growth (Pierotti & Annet, 1987; 1990). Consequently there is a strong positive relationship between the amount of fish taken by pairs and their breeding success, breeding lifespan, total egg production, total hatchling production and lifetime fledging production (Annett & Pierotti, 1999). Thus, Western Gulls that increased the fish content in their diet had a higher reproductive output than gulls that continued to feed on refuse (Annett & Pierotti, 1999). These results suggest that if a larger proportion of the population switched to readily available fish, there would be an increase in reproductive success and hence an increase in population size.

Similar impacts of a diet of low nutritional value (human refuse) have been found for Silver Gulls in Hobart, Tasmania. Like many urban gull populations, this population relies on discarded food such as potato chips and bread, unlike nearby 'natural' colonies on the Furneaux Island Group that eat berries, insects and crustaceans (Auman *et al.*, 2008). The Hobart gulls have a greater body mass and higher cholesterol level compared to the Furneaux Island gulls, and while they produce more eggs, they are likely to fledge fewer chicks due to their nutritionally inadequate diet (Auman *et al.,* 2008).

While some species of gulls actively forage for fish (Annett & Pierotti, 1989; 1999), others have become heavily reliant on fisheries discards (Oro *et al*., 1995; 1996; 1999; Oro, 1996; Huppop & Wurm, 2000; Martinez-Abrain *et al.*, 2002; Votier *et al.,* 2004). The readily accessible supply of fisheries discards has been shown to significantly influence the timing of egg laying, egg volume and size, clutch size, nest desertion, hatching success and overall breeding success in many species of gulls (Oro *et al*., 1995; 1996; 1999; Oro, 1996; Votier *et al.,* 2004). Where trawling moratoriums have overlapped with egg production and egg laying, the body condition of laying females has been shown to decline leading to reduced reproductive output (Oro *et al.,* 1999). This was exhibited in a population of Audouin's Gull in the Ebro Delta (NE Spain), where the fishing moratorium coincided with a three week delay in laying, and decreases in egg size, modal clutch size, hatching success and hatchling weight (Oro, 1996; Oro *et al*., 1996). However, an even more detrimental impact occurred when the moratorium overlapped with the chick rearing phase when a readily available supply of quality food is essential for chick survival (Oro *et al*., 1995; 1996; Oro, 1996). In this period, the overall breeding success for Yellow-legged Gulls decreased by 46% (Oro *et al*., 1995) and by 48% for the Audouin's Gull (Oro *et al*., 1996).

These findings suggest that high quality food seems to be more important during chick rearing than egg production, however, clutch size and high quality eggs can still be a determining factor in breeding success. Larger and better provisioned eggs are usually produced by more experienced parents with a more nutritious diet (Parsons, 1972; Mills, 1979; Bolton, 1991; Verboven *et al.,* 2005). However, larger eggs can also be produced in times of poor food supply, which may act as an insurance to enhance the survival of nestlings hatched before peak food abundance (Mills, 1979; Monaghan & Nager, 1997). Interestingly, larger is not always better when it comes to eggs. When food is short, females may produce eggs that have a small yolk but large albumen, resulting in heavier eggs but decreased developmental maturity of the hatchling (Monaghan & Nager, 1997). Clutch size and the number of clutches laid in a season are also influenced by food abundance. To a point, abundant food can increase the clutch size produced by a female bird (Oro *et al*., 1995; 1996; 1999; Oro, 1996; Monaghan & Nager, 1997; Votier *et al.,* 2004). However, clutch size is also limited by the number of young that parents can successfully lay, incubate and rear to independence (Monaghan & Nager, 1997). An abundant source of food can also create a protracted laying season, with more than one clutch produced by breeding pairs per season, however, unless food is available throughout the chick rearing period, the protracted season may not ensure a greater reproductive output (Nicholls, 1974; Wooller & Dunlop, 1979; Smith, 1995). Therefore, the quality of parental input before and during chick rearing plays a vital role in overall reproductive output (Bolton, 1991; Monaghan & Nager, 1997; Risch & Rohwer, 2000).

As mentioned in previous chapters, populations of Silver Gulls across Australia have increased substantially and this has been attributed to their exploitation of anthropogenically created food sources (Smith, 1995). This has resulted in a protracted breeding season, resulting in a high reproductive output, with some populations breeding almost year round, and having three to four laying peaks, where they would have previously had one to two (Nicholls, 1974; Wooller & Dunlop, 1979; Smith, 1995). However, the extra laying peaks are not always successful in producing chicks and in some cases, eggs laid in the latter part of the season may not be successful at all (Smith & Carlile, 1992; Smith, 1995). Some of these populations, such as that on Big Island, NSW (50,000 nesting pairs) have plateaued, having reached the carrying capacity of their food resource (Smith, 1995).

In summary, food resources are a key regulator of reproduction because they provide the energy necessary for reproduction, but they can also be the limiting factor resulting in a population plateauing at its carrying capacity (Smith, 1995).

In Port Lincoln, the Silver Gull population had risen from about 3,300 nesting pairs in 1999 (Farlam, 2003) increasing to 10,300 in 2003 (Harrison, 2003) to as high as

27,800 nesting pairs in 2005 (Chapter 5). Many of these gulls frequent the Southern Bluefin Tuna (SBT) farms off the coast of Port Lincoln during their breeding season. These gulls also forage in urban areas within the city, in particular the refuse depot, although in much smaller numbers than the SBT farms. The gulls commonly scavenge the high quality, lipid and protein rich baitfish fed to the tuna (Harrison, 2003).

The mean clutch size (2.35) of this population was about one egg greater than that of the reference population in the Coorong (1.41) with no access to tuna feed. However, mean egg weight was significantly greater for the Coorong gulls (Coorong: 40g; PL: 38.8g) (Harrison, 2003). These gulls may have exhibited a trade off between clutch and egg size. The diet of the Coorong gulls was presumably of a lesser quality than the Port Lincoln gulls, resulting in these gulls producing fewer, larger, better provisioned eggs with enough nutrients to ensure development through to hatching, whilst the Port Lincoln gulls produced smaller eggs, but more of them.

The breeding season (March-October) of this population mimics that of the SBT farming season (February-September/October) and is 6-7 months earlier than any other known colonies in the state (Ottaway *et al.,* 1988; Harrison, 2003). Historically, the population in the area bred from May to September (1987-1989), but this was lengthened to April to November in 1999 and 2000 (Farlam, unpublished data). This protraction coincided with the tuna pens being relocated from inside of Boston Bay to near Rabbit Island in the Rabbit Island Tuna Zone in 1998. This timing of breeding differs markedly from gulls in the Coorong, which breed from August onwards (Harrison, 2003) and other sites in the State which breed anywhere from

July to March or late August to late February (Higgins & Davies, 1996).

The opportunistic nature of this species has allowed them to take full advantage of tuna feed as a food source with an estimated 60t of feed consumed by Silver Gulls from the one company surveyed in 2003 (Harrison, 2003). As mentioned previously, this population of gulls had almost double the mean clutch size (albeit with a lower egg weight) than a reference population of gulls in the Coorong (Harrison, 2003). Thus, the tuna industry is probably directly influencing the reproductive output of these gulls through the availability of this high quality food. Further, the majority of the breeding Silver Gulls should have access to this food, not just the older, more experienced birds, and so the reproductive success of the entire population should be high (compared to a site with little to no access to human derived food). This should occur because a diet rich in fish has been shown to increase female body condition, egg size, clutch size, chick size, chick survival and fledging success (Annett & Pierotti, 1989; 1999; Bosch *et al*. 1994; Oro *et al*., 1995; 1996; 1999; Oro, 1996; Votier *et al.,* 2004).

Aims

The aims of this study were:

- To assess the reproductive output parameters of the Port Lincoln Silver Gull population including clutch size, egg volume, hatching success, fledging success and mortality rate relative to two reference sites.
- To record, monitor and compare the breeding season timing and length of both the Port Lincoln Silver Gulls and those of reference populations.

Hypotheses

H0: The location of Silver Gull breeding colony (Port Lincoln or reference colonies) will have no impact on reproductive output (as determined by egg volume, clutch size, hatching success and/or fledgling survival).

HA: The reproductive output of the Port Lincoln Silver Gulls will be different to that of the reference site gulls.

H0: There will be no difference in egg quality (as determined by egg volume) between the sites (Port Lincoln vs. reference).

HA: Egg quality will be significantly different between the two sites.

H0: There will be no difference in breeding season timing and length for the Port Lincoln and reference site gulls.

HA: The breeding season of the Port Lincoln gulls will be different to that of the reference gulls.

6.2 Methods

6.2.1 Study Area

The Port Lincoln breeding sites included Rabbit and Sibsey Island in 2004 and 2005 and Rabbit and Louth Island in 2006. Sibsey Island was not used as an experimental breeding site in 2006 because of access difficulties, particularly during windy conditions. Due to small population sizes, variability in breeding and inaccessibility breeding colonies on Winceby Island, Donington Island and Boston Island (Fanny Point) were not monitored (Figure 6.1).

The reference sites included Pelican Island (Outer Harbour, Adelaide) in 2004, Venus Bay, Island C in 2004 and 2005 and Lipson Island in 2004-2006. Pelican Island at Outer Harbour was chosen as a reference to compare the reproductive output of a population known to be reliant on human refuse to that of other reference gulls (reliant on ‘natural’ food) and the Port Lincoln gulls. Island C was to be used in 2006, but the breeding season was missed because the gulls commenced breeding two months earlier than in previous years, presumably due to the unseasonable warm winter. The reference population at the Coorong (South East, South Australia) used in my Honours study in 2003 is also mentioned in the results.

Rabbit Island has been the main breeding colony for Silver Gulls in the Port Lincoln area for several years, except for the 2003 breeding season, where the gulls moved to Sibsey Island. The next year, Rabbit Island was recolonised to become the main breeding colony, whilst the Sibsey Island colony remained stable.

Louth Island was included in this project in 2006, due to its small population of Silver Gulls being included in the egg oiling trial (Chapter 8). Reproductive output data were collected for the control nests during the trial and have been included in this chapter.

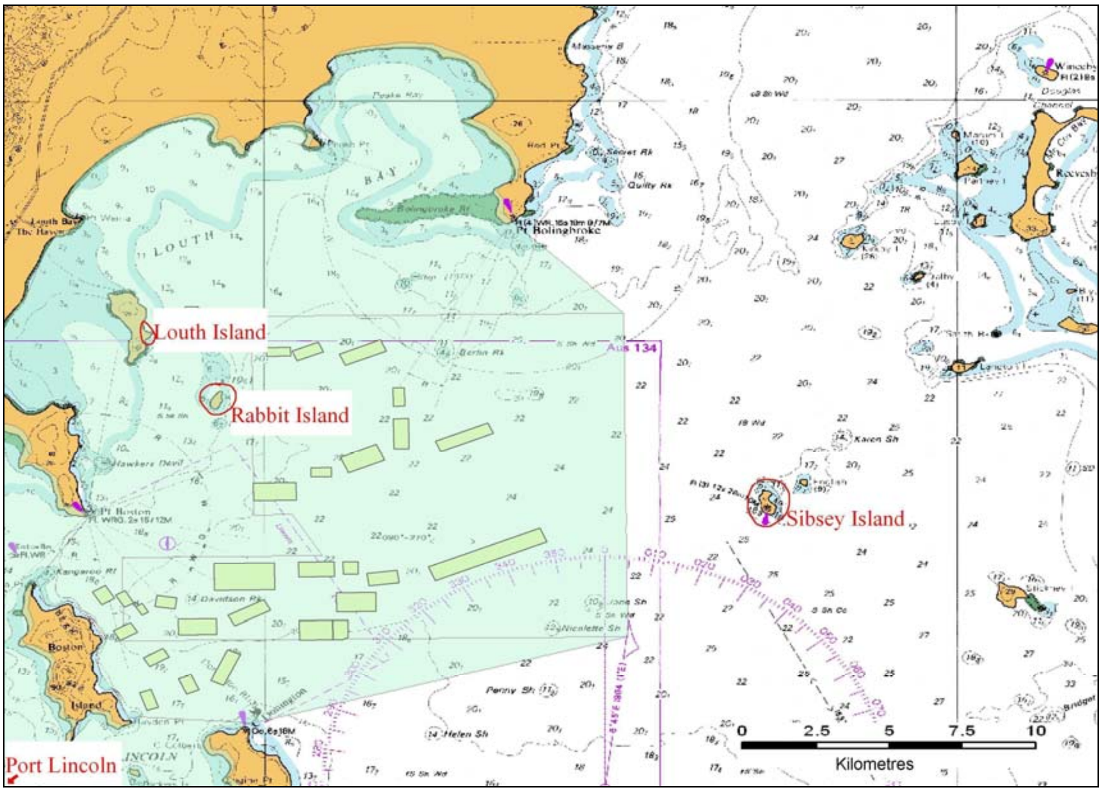

Figure 6.1: (also figure 2.3). The Port Lincoln Silver Gull breeding colony islands (red circles) and the tuna farms (green rectangles) 2005 chart. Source: PIRSA Aquaculture.

6.2.2 Determining Breeding Season Length

The length of the breeding season was determined by visiting each breeding colony in the early and late months of the breeding season. Colonies were visited at the time they were known to have bred in previous years. At the start of the season, in most cases nest territories had been established and new nests had been made. If nests were present, 20 days was subtracted from that date to determine territory establishment, as Silver Gulls generally lay approximately 19 days after territory establishment and a few days to a week after completion of the nest (Smith & Carlile, 1992). In these instances nests were monitored approximately weekly until eggs were present. If eggs were already present, they were monitored approximately weekly until hatched and then 26 days was subtracted to establish egg laying and a further 20 days for territory and nest establishment. As we could not visit the colonies as often as we liked, the approximate date obtained was an observation not a statistic, and therefore the month that the date fell in was used instead of that specific date.

The end of the season was established by monitoring nesting and was determined as when no new nests or eggs were present, all nests looked abandoned and only older chicks were present at the colony. Once again, the month, not a specific date was used.

6.2.3 Assessing Reproductive Output

The reproductive output of Silver Gulls from all study sites was assessed during the 2004-2006 breeding seasons (Table 6.1) and incorporated data from 2003. The breeding season was divided into three parts; early, mid and late, to determine whether there were any differences in reproductive output parameters over the season (Table 6.1).

Table 6.1: Months islands were visited during the study. N=number of times each island was visited.

	2004	**2005**	**2006**	**Breeding Season**	**Time of Laying**
Rabbit Island	March-July (n=4)	Feb-July (n=8)	April-Sept (n=17)	January-October	**Early**: Jan-April **Mid**: May-July **Late**: Aug-Oct
Sibsey Island	July-Sept (n=6)	Feb-July (n=8)	N/A	January-October	**Early**: Jan-April **Mid**: May-July **Late**: Aug-Oct
Louth Island	N/A	N/A	July-Sept (n=8)	?	N/A
Pelican Island	Oct (n=2)	N/A	N/A	July/Aug-?	N/A
Lipson	April-June	April-Sept	May-July	April-	**Early**:

Island	(n=16)	(n=16)	(n=6)	August	April/May **Mid**: June/July **Late**:Aug/Sept
Island C	Oct-Nov (n=3)	Nov-Dec (n=6)	N/A	Sept/Oct-Nov/Dec	N/A

6.2.3.1. Parameters Measured

The following reproductive output parameters were measured:

- Clutch Size
- Egg Volume
- Hatching Success
- Fledging Success

And the following parameters calculated:

- Chick Survival Probability
- Estimated Overall Reproductive Output

See Chapter 2.4.2 for details of the methodology used for determining each of these variables except Estimated Overall Reproductive Output (below).

Although egg weight was measured as a reproductive output parameter, it was not included in the results section but in the Appendix. Due to the inconsistent intervals the islands were accessed at, it was not always possible to determine the stage of incubation of each egg that was weighed. As Silver Gull eggs lose weight (mainly due to water loss) at a constant rate during incubation (Wooller & Dunlop, 1980), egg weight would vary at different times of incubation, therefore the results obtained would not be comparable.

Estimate of Overall Reproductive Output

Combining the above reproductive output data (clutch size, hatching success and chick survival) made it possible to calculate an estimated output (number of chicks produced) per nest and therefore an estimated population increase per year. This parameter was calculated with the following equation:

(mean clutch size **X** hatching success) **X** chick survival = estimate of no. of chicks fledged/produced per nest.

6.2.4 Statistical Analysis

A Kruskall Wallis Test was used to analyse for any differences in median clutch size between the Port Lincoln and reference gulls. A series of Mann Whitney U Tests was undertaken to identify differences in clutch size between individual years (Bonferroni Adjustment on p value, significance $p<0.008$). These tests were also used to ascertain any differences in clutch size over the breeding season.

Univariate ANOVA was used to look for differences in mean egg volume between the Port Lincoln, natural reference and Adelaide reference sites. Individual egg volumes within nests were nested (per clutch to take into account similarity within nests/clutches), and nests from sampling groups were also nested to account for non-independence between sampling groups. The estimated means were used to analyse the data instead of the actual means. The same approach was also undertaken to test for differences in mean egg volume between years and over the breeding season. Post hoc comparisons were performed using the Tukey HSD method.

Hatching success was reported as a percent of eggs hatched per clutch and as a categorical success which was reported in three categories, none, partial and complete success. No success (0% eggs hatched), partial success (33.33%, 50% or

66.67% hatched), and full success (100% hatched).

Fishers Exact Test or Chi Square Analysis was used to test for differences in the proportion of nests with a success of none, partial or complete between the Port Lincoln and reference site gulls. These same analyses were also performed to test for differences in categorical egg hatching success between years at each site (Bonferroni Adjustment on p value, significance measured at p<0.017).

The Test of Proportions in Microsoft Excel was used to test for the difference in mean percent hatching success between the sites and to analyse for difference in mean percent hatching success between years at each site (Bonferroni Adjustment on p value, significance measured at p<0.017). This test is used to compare two proportions using the observed sample proportion (p) and the sample size of the proportion (n). The formulae below calculate a p-value and a z-statistic for the comparison.

$$z = \frac{(p_1 - p_2)}{\sqrt{(p_1 * (1 - p_1) / n_1) + (p_2 * (1 - p_2) / n_2)}}$$

p-value = 2*(1-normal distribution) *z))

The p-value is the only value reported within the results. See Chapter 8.2 in Moore & McCabe (2006) for further information.

The Cormack-Jolly-Seber Model (live recaptures only) in Program MARK was used to estimate survival rate of chicks to fledging. The data were divided into Port Lincoln and reference populations for each year and run individually as the specific timing of observations were not the same for each. The entire season’s data for each site and year were combined in the one model and the variation in time interval was accounted for by entering in the time between each encounter occasion to that model. A Burnham Model (live and dead recaptures) was applied to the data, however, the inclusion of the dead recaptures did not alter the conclusion. In addition, there was a very small sample size for dead recaptures and so the live recapture only model was chosen. A bootstrap goodness of fit test was performed on the data to determine whether the model fitted. The end result was a daily probability of survival.

The estimate of overall reproductive output per nest data were qualitative only and not analysed statistically as there were only two data points (Port Lincoln vs. reference).

6.3 Results

6.3.1 Breeding Season

The breeding season of the Port Lincoln Silver Gull population encompassed January to October in the 2004, 2005 and 2006 breeding seasons. In this protracted season there are at least three peak laying periods (January, April and July) and viable eggs were found from January to August.

The breeding season of the Port Lincoln gulls starts 4-10 months earlier than any other population of gulls in South Australia. Lipson Island, which is approximately 62km from Port Lincoln, 43km from the nearest tuna farm and whose gulls do not eat tuna feed, start breeding in April and finish in about July/August (personal observation during 2004-2006). There were approximately two laying peaks that occurred each season at these sites. Breeding colonies such as Venus Bay, Outer

Harbour and the Coorong (visited during my Honours project) also bred much later than the Port Lincoln gulls. Gulls in Venus Bay bred from September/October to November/December (2004 and 2005). These gulls only produced one clutch of eggs and did not appear to replace lost clutches. The Outer Harbour gulls were visited twice during 2004 and started breeding around July/August in this year. The Coorong was visited once during 2003 and initiated breeding in about August of that year.

Table 6.2: Silver Gull breeding population dynamics for several South Australian sites. ND = not determined. Data from 1987-2000 from Farlam (2003). 2003 data from Harrison (2003).

	Year	Start Month	End Month	Total Months	Laying Peaks
Port Lincoln	1987-1989	May	September	5	?
	1999-2000	April	November	8	?
	2003	February	Oct/Nov	10	?
	2004-2006	January	October	10	Jan, April, July (and late Aug?)
Lipson Island	2004-2006	April	August	5	May, July
Venus Bay	2004-2005	Sept/October	December	3	October
Outer Harbour	2004	August	ND	ND	ND
Coorong	2003	August	ND	ND	ND

6.3.2 Reproductive Output: Port Lincoln vs Reference Gulls

6.3.2.1 Clutch Size

The mean clutch size was very similar for the Port Lincoln gulls and reference gulls from 2004-2006. The median clutch size was also similar with no significant difference found for clutch size between the study sites (Tables 6.3 & 6.4: 2004: Kruskall Wallis: $\chi^2_2 = 0.51$, p=0.775; 2005: Mann Whitney U: Z=-1.95, p=0.051; 2006: Z= -1.94, p=0.052)). However, the results for 2005 and 2006 do suggest a weak significance with the Port Lincoln sites tending to be higher.

There was a significant difference in mean clutch size between the Port Lincoln gulls and the Coorong gulls in 2003 ($F_{1, 294}=85.4$, $p<0.001$) (Honours data: Harrison, 2003), although this population was not used as a reference for the latter years.

Table 6.3: Clutch size data for the Port Lincoln gulls for all years of research (Islands: S=Sibsey, W=Winceby, D=Donington, R=Rabbit, Lo=Louth) (Time of season: E=Early, M=Mid, La=Late).

Clutch Size Pt Lincoln Gulls	2003 (S, W & D)	2004 (S & R)	2005 (S & R)	2006 (R & Lo)
Mean	2.34	2.31	2.31	2.47
Mean (time of season)	-	2.4 (E), 2.3 (M), 2.2 (La)	2.5 (E), 2.3 (M), 2.3 (La)	2.5 (E), 2.5 (M), 2.4 (La)
Median	2	2	2	3
Median (time of season)	-	3 (E), 2 (M), 2 (La)	3 (E), 2 (M), 2 (La)	3 (E), 3 (M), 2 (La)
Mode	3	2	2	3
Std Dev	0.73	0.69	0.66	0.57
Range	1-3	1-3	1-3	1-3
N	233	134	195	251

Table 6.4: Clutch size data for the reference gulls for all years of research (C=Coorong, P=Pelican Island (Adelaide), V=Venus Bay, L=Lipson Island) (Time of season: E=Early, M=Mid, La=Late).

Clutch Size Reference Gulls	2003 (C)	2004 Adelaide (P)	2004 Reference (V & L	2005 (V & L)	2006 (L)
Mean	1.41	2.37	2.25	2.15	2.27
Mean (time of season – L only)	-	-	N/A (E only)	2.2 (E), 2.1 (M), 2 (La)	2.2 (E), 2.3 (M), N/A (La)
Median	1	2	2	2	2
Mean (time of season – L only)	-	-	N/A (E only)	2 (E), 2 (M), 2 (La)	2 (E), 2 (M), N/A (La)
Mode	1	3	2	2	2
Std Dev	0.64	0.67	0.70	0.71	0.64
Range	1-3	1-3	1-3	1-3	1-3
N	63	30	55	122	48

Port Lincoln Gulls

The mean clutch size for the Port Lincoln gulls was very similar for all years of research as was the median clutch size (Kruskall Wallis: χ^2_3 =6.64, p=0.084) (Table 6.3). Therefore the proportion of 1, 2 and 3 egg clutches was also similar between years (Figure 6.2).

There was no significant difference in median clutch size over the different parts of the laying season (early, mid or late laying) for each year of research (Table 6.3: Kruskall Wallis: 2004: χ^2_2 =1.59, p=0.451; 2005: χ^2_2 =3.2, p=0.202; 2006: χ^2_2 =3.12, p=0.210).

Reference Gulls

There was no significant difference in median clutch size for the reference gulls between the three years (2004-2006) of research (Table 6.4: Kruskall Wallis: χ^2_2 =1.4, p=0.0597). The mean clutch size for the reference gulls of the Coorong used in 2003 was much smaller than that of the other reference gulls populations used for the other three years. However, as the Coorong gulls were not studied from 2004-2006, this data was not included in the analysis.

As the median clutch size for 2004, 2005 and 2006 were not significantly different, the proportion of 1, 2 or 3 eggs clutches did not differ between years for the reference site gulls (Figure 6.2).

There was a significant difference in median clutch size for the Lipson Island gulls over the laying season (early, mid or late laying) in 2005 (Table 6.4: Kruskall Wallis: χ^2_2 =22.15, p<0.0001), but not for 2006 (χ^2_1 =0.33, p=0.568). In 2005, these differences were between early and mid season (Mann Whitney U: Z= -3.89, p<0.0001) and early and late season (Z= -4.01, p<0.0001), but not between mid and late season (Z= -0.27, p=0.787).

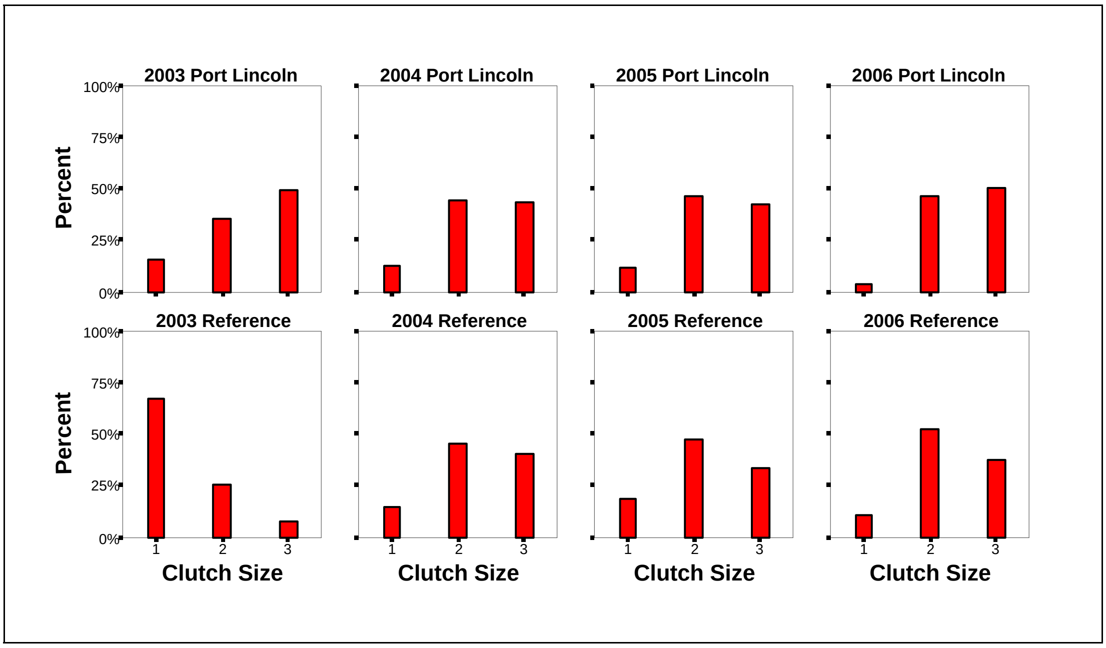

Figure 6.2: A comparison of the proportion of nests with a clutch size of 1, 2 or 3 for Port Lincoln and reference site gulls over the four years of research. 2003 data from Harrison (2003).

6.3.2.2 Egg Volume

The mean egg volumes (cm^3) of the reference gulls were consistently larger than those of the Port Lincoln gulls (Univariate ANOVA: $F_{1, 861}$= 9.86, p=0.002); this was significant for 2004 ($F_{1, 1298}$=4.76, p= 0.023) and 2005 ($F_{1, 1298}$= 8.97, p=0.003) but not for 2006 ($F_{1, 1298}$ = 2.02, p=0.155) (Table 6.5 & 6.6, Figure 6.3). The 2004 season had two reference sites, Adelaide and the natural reference. Post-hoc comparisons found the significant differences amongst sites to be between the natural reference gulls and the two other sites (Port Lincoln: p<0.0001; Adelaide: p=0.001). There was no significant difference between the mean Port Lincoln egg volume and the mean Adelaide site egg volume (p=0.993).

Table 6.5: Egg volume (cm^3) data for the Port Lincoln Gulls for all years of research (Islands: S=Sibsey, R=Rabbit, Lo=Louth) (Time of season: E=Early, M=Mid, La=Late).

Egg Volume Port Lincoln Gulls	**2004**	**2005**	**2006**
	(S & R)	(S & R)	(R & Lo)
Mean	38.77	39.12	38.45
Mean (time of season)	38.1 (E), 39.3 (M), 39.1 (La)	39.5 (E), 39.03 (M), 38.1 (La)	38.6 (E), 38.5 (M), 38.1 (La)
Estimated Mean	38.81	39.09	38.44
Median	38.68	39.23	38.27
Mode	37.96	38.68	36.55
Std Dev	3.27	3.29	3.33
Range	30.38-49.00	29.77-47.62	29.04-50.03
N	295	449	616

Table 6.6: Egg volume (cm^3) data for the Reference Gulls for all years of research (P=Pelican Island (Adelaide), V=Venus Bay, L=Lipson Island) (Time of season: E=Early, M=Mid, La=Late).

Egg Volume Reference Gulls	**2004**	**2004**	**2005**	**2006**
	Adelaide (P)	(V & L)	(V & L)	(L)
Mean	38.73	40.06	40.27	39.29
Mean (time of season – L only)	-	N/A (E only)	41.4 (E), 39.4 (M), 39.3 (La)	39.6 (E), 39.1 (M), N/A (La)
Estimated Mean	38.44	40.29	39.96	38.93
Median	39.23	40.11	40.30	38.96
Mode	39.98	39.39	39.39	36.67
Std Dev	3.42	2.91	3.73	3.73
Range	31.5-45.26	34.03-47.53	29.59-55.94	29.82-47.01
N	71	123	256	107

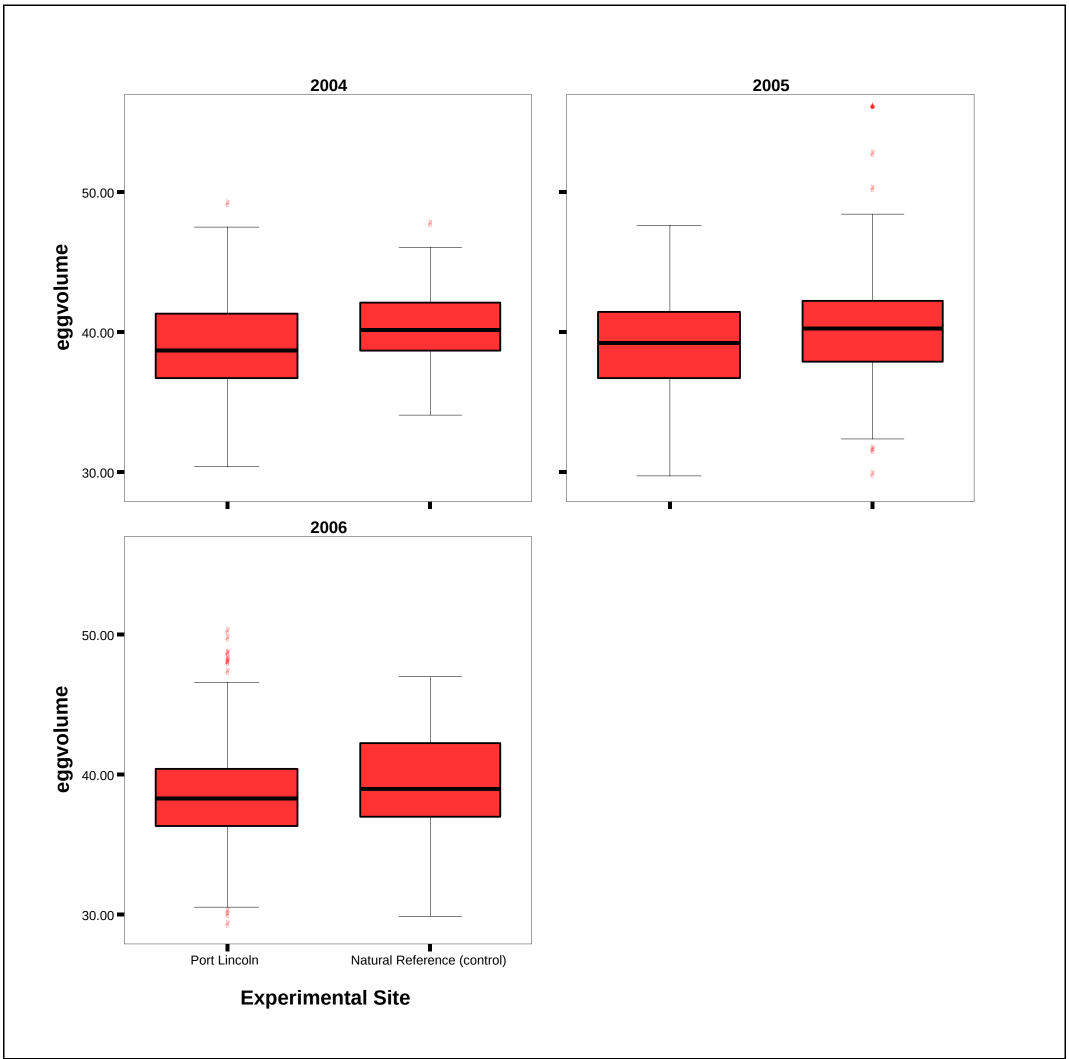

Figure 6.3: A comparison of mean egg volume (cm^3) for each site over the three years of data collection.

Port Lincoln Gulls

The mean egg volume for the Port Lincoln gulls was very similar for the three years of data collection (2004-2006) with no significant difference between years (Table 6.5: $F_{2, 406}$= 2.804, p=0.062). However, there were significant differences in egg volume over the breeding season (early, mid or late laying) for each year (Table 6.5: $F_{3, 875}$= 7.624, p<0.0001). Post hoc analyses showed these differences to be between the early and mid laying in 2004 (p=0.014), 2005 (p=0.017) and 2006 (p<0.0001) and mid and late laying in 2004 (p=0.018). Analyses could not be computed for early and late and mid and late laying in 2005 and 2006.

Although there was a significant difference in egg volume over the breeding season, there was no consistent increase or decrease in egg volume as the season progressed over the three years.

Reference Gulls

Similarly, the mean egg volume for the reference gulls was very similar for the three years of data collection (2004-2006) with no significant difference between years (Table 6.6: $F_{2,174} = 2.28$, p=0.105). There was also no significant difference in egg volume over the breeding season (early, mid or late laying) for each year (Table 6.6: $F_{2,244} = 3.12$, p=0.190).

6.3.2.3 Hatching Success

The mean hatching success of the Port Lincoln gulls was consistently higher than the reference gulls for all years of research (Tables 6.7 and 6.8); this was significant for 2005 (Excel Test of Proportions: p=0.0028) and 2006 (p=0.019), but not 2004 (p=0.415). However, the median only differed in the 2006 season.

Table 6.7: Hatching success (% eggs hatched per clutch) of Silver Gulls from the Port Lincoln area over the three years of research (Islands: S=Sibsey, R=Rabbit, Lo=Louth) (Time of season: E=Early, M=Mid, La=Late).

Hatching Success (%) Port Lincoln Gulls	**2004** (R & S)	**2005** (R & S)	**2006** (R & Lo)
Mean	84.94	81.34	80.00
Mean (time of season)	92 (E), 76.2 (M), 78.8 (La)	N/A (M only)	70.5 (E), 85.1 (M), 88.5 (La)
Median	100	100	100
Mode	100	100	100
St Dev	27.67	34.49	34.23
Min-Max	0-100	0-100	0-100
N	52	67	105

Table 6.8: Hatching success (% eggs hatched per clutch) of Silver Gulls from the reference sites over the three years of research (V=Venus Bay, L=Lipson Island) (Time of season: E=Early, M=Mid, La=Late).

Hatching Success (%) Reference Gulls	**2004** (V & L)	**2005** (V & L)	**2006** (L)
Mean	78.76	61.25	59.76
Mean (time of season – L only)	N/A (E only)	87.2 (E), 28.6 (M), 34.5 (La)	63.3 (E), 56.3 (M), N/A (La)
Median	100	100	66.67
Mode	100	100	100
St Dev	36.53	45.52	41.83
Min-Max	0-100	0-100	0-100
N	51	106	41

Each year's data were also analysed for categorical success per nest (0%=none, 33.33-66.67%=partial, 100%=complete). There was no significant difference in the ratio of these categories between the Port Lincoln and reference gulls for 2004 (Fishers Exact: p=0.32). However, significant differences were found for the 2005 (Chi Square: $\chi^2_2 = 9.19$, p=0.010) and 2006 data ($\chi^2_2 = 8.95$, p=0.011). The 2005 data showed that the Port Lincoln and reference gulls had a similar ratio of nests with partial success, but the Port Lincoln gulls had a significantly higher ratio of nests with complete success and the reference gulls a significantly higher number of nests with no success ($\chi^2_1 = 9.14$, p=0.003). The 2006 data showed that the reference gulls had a larger proportion of no and partial success nests and a smaller proportion of complete success nests compared to the Port Lincoln gulls ($\chi^2_2 = 8.95$, p=0.011).

Port Lincoln Gulls

There was no significant difference in the hatching success found for the Port Lincoln gulls between 2004 and 2006 (Excel Test of Proportions: 2004vs2005, p=0.60; 2005vs2006, p=0.83; 2004vs2006, p=0.43). Similarly, there was no significant difference in the ratio of each hatching success category between years

(χ^2_4 = 2.47, p = 0.650) (Figure 6.4).

There was also no significant difference in mean % hatching success over the breeding season (early, mid or late laying) for each year (Table 6.7: Excel Test of Proportions: (2004: EvsM p=0.208, EvsL p=0.325, MvsL p=0.877; 2005 N/A; 2006: EvsM p=0.168, EvsL p=0.068, MvsL p=0.748).

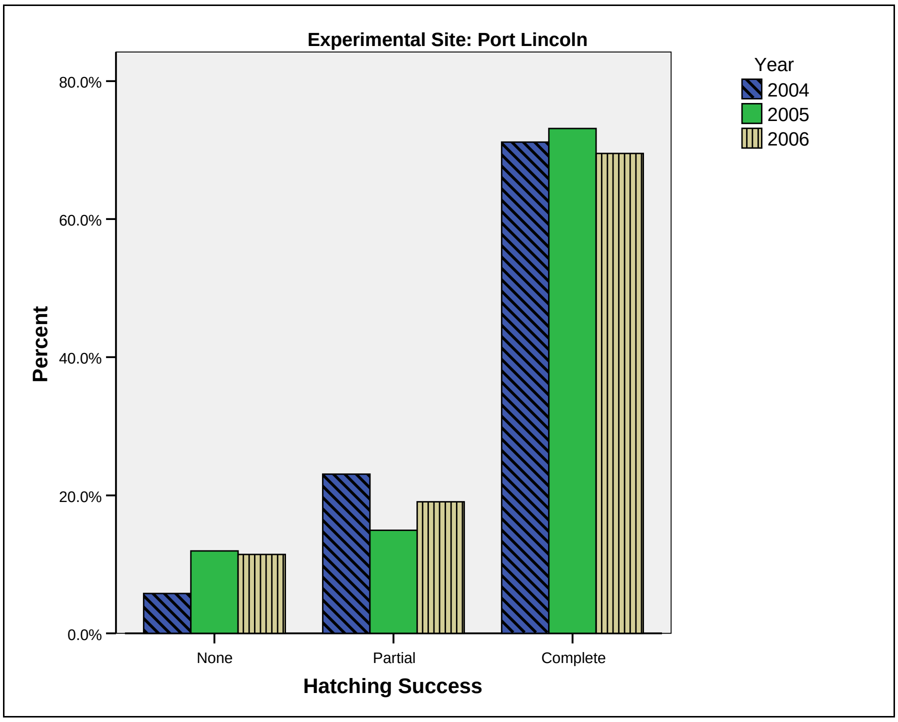

Figure 6.4: A comparison of percentage of the data in each hatching success category for Silver Gulls in the Port Lincoln area over the three years of data collection.

Reference Site Gulls

There was a significant difference in mean hatching success between years for the reference gulls. These differences were for 2004 and 2005 (Excel Test of Proportions: p=0.018), and 2004 and 2006 (p=0.047). There was no significant difference between 2005 and 2006 (p=0.87) (Table 6.8). There was also a significant difference in the ratio of each hatching success category between years (Chi Square: χ^2_4 = 11.95, p = 0.018). These differences were found to be between hatching success in 2004 and 2005 ($\chi^2_2 = 6.04$, p = 0.049), 2004 and 2006 ($\chi^2_2 = 6.68$, p = 0.035) but not between 2005 and 2006 ($\chi^2_2 = 5.25$, p = 0.073), as seen in Figure 6.5 which suggests that the ratio of complete success clutches decreased for each year of research.

There was also a significant difference in mean % hatching success over the breeding season (early, mid or late laying) for 2005 (early vs mid and late season only) but not 2006 (Table 6.8: Excel Test of Proportions: (2004: N/A; 2005; EvsM p<0.0001, EvsL p<0.0001, MvsL p=0.658; 2006: EvsM p=0.647).

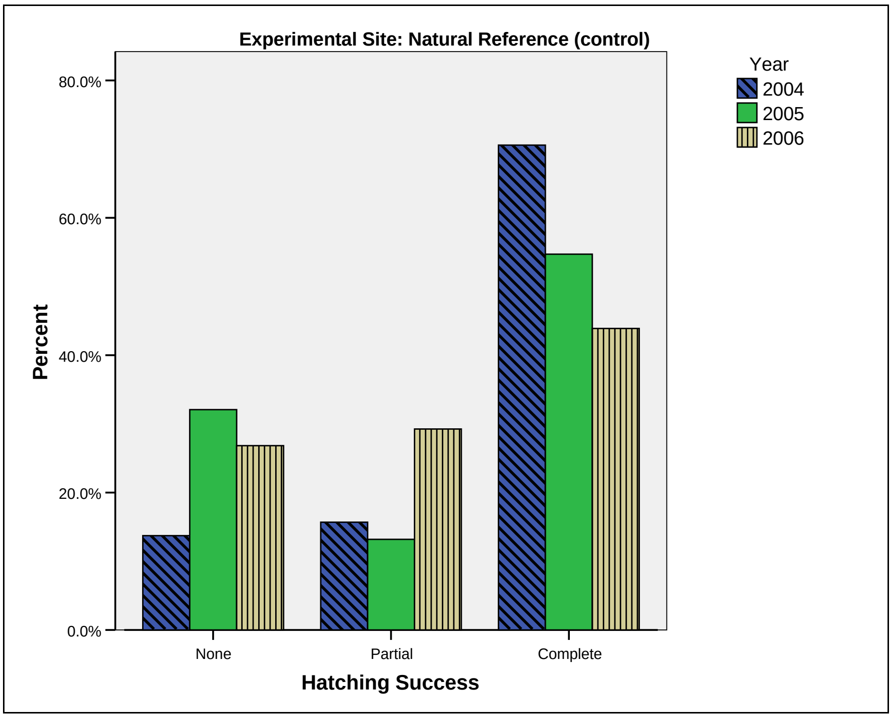

Figure 6.5: A comparison of percentage of the data in each hatching success category for the reference gulls over the three years of data collection.

6.3.2.4 Chick Survival Rate to Fledging

The daily estimated chick survival was significantly larger for the Port Lincoln population than the reference population in 2004 and 2006, with no overlapping of confidence intervals (Table 6.9 and 6.10). However, survival was similar for both populations in 2005, with an overlap in confidence intervals. Refer to the Appendix for the full model results.

Table 6.9: Port Lincoln chick survival estimates and model weightings.

	Model	AICc Weight	Survival Estimate	Lower 95% CI	Upper 95% CI
2004	phi(t) p(t)	0.99944	0.9683	0.9589	0.9755
2005	phi(t) p(t)	0.9992	0.9685	0.9571	0.9769
2006	phi(.) p(t) phi(t) p(t)	0.5907 0.4072	0.9663	0.9529	0.9760

Table 6.10: Reference chick survival estimates and model weightings.

	Model	AICc Weight	Survival Estimate	Lower 95% CI	Upper 95% CI
2004	phi(.) p(.)	0.9110	0.8698	0.8166	0.9093
2005	phi(t) p(t)	0.8864	0.9596	0.9369	0.9747
2006	phi(t) p(t) phi(t) p(.)	0.6247 0.1945	0.8669	0.8101	0.9087

Port Lincoln Gulls

Daily chick survival for the Port Lincoln population was estimated at ~0.97 for all three years of research with overlapping confidence intervals (Table 6.9), indicating survival was similar for all three years. There was evidence of time variance in survival over the season in 2004 and 2005 as this was the model with the highest weighting (phi(t) p(t) = survival and encounter rate both time dependent). In 2006 there was slight evidence of time variance as both the phi(.) p(t) (survival constant over time, encounter rate time dependent) and phi(t) p(t) models had similar weightings.

Although there was evidence of time variance for survival rate over the season, the trends were not evident due to the small sample sizes.

Reference Gulls

Daily chick survival for the reference population was estimated at ~0.87 for 2004 and 2005, but was higher (~0.96) for 2006 (Table 6.10). The confidence intervals for 2004 and 2006 overlapped, indicating that these years had similar results. However, the confidence intervals of 2005 did not overlap with those for 2004 or 2006, indicating that this years results were significantly different. There was no evidence of time variance in chick survival rate over the 2004 season (phi(.) p(.) = survival and encounter rates constant over time), however, there was evidence for this in 2005 and 2006. Although the time variance model exhibited the highest weighting, due to the small sample sizes there was no real trend evident.

6.3.2.5 Estimate of Overall Reproductive Output

The number of chicks produced per nest for the Port Lincoln gulls was 1.90 in 2004, 1.82 in 2005 and 1.92 in 2006 (Table 6.11).

Table 6.11: Estimate of overall reproductive output per nest of the Port Lincoln gulls for each year of research.

Port Lincoln Gulls	**2004**	**2005**	**2006**
Clutch Size	2.31	2.31	2.47
Hatching Success (%)	84.94	81.34	80
No. of chicks hatched per nest	1.96	1.88	1.98
Chick survival rate	0.97	0.97	0.97
Fledged chick output per nest	**1.90**	**1.82**	**1.92**
Confidence Intervals	1.89-1.91	1.81-1.83	1.92-1.93

The number of chicks produced per nest for the reference site gulls was 1.53 in 2004, 1.26 in 2005 and 1.17 in 2006 (Table 6.12).

Table 6.12: Estimate of overall reproductive output per nest of the reference gulls for each year of research.

Reference Site Gulls	**2004**	**2005**	**2006**
Clutch Size	2.25	2.15	2.27
Hatching Success (%)	78.76	61.25	59.76
No. of chicks hatching per nest	1.77	1.32	1.35
Chick survival rate	0.87	0.96	0.87
Fledged chick output per nest	**1.53**	**1.26**	**1.17**
95% Confidence Intervals	1.48-1.62	1.23-1.27	1.11-1.21

6.4 Discussion

The importance of tuna feed as a food source is reflected in the timing of the breeding season of the Port Lincoln Silver Gull population which has become protracted over about the last decade. In addition, the estimated overall reproductive output (chicks per nest) of this population was ~25%-50% greater than that of a reference population with no access to tuna feed and this appears to be directly related to the observed rapid increase in population size over the last eight years.

Rabbit Island has traditionally been the major breeding colony for Silver Gulls in the Port Lincoln area from 1987 to 1989, with a breeding season between May to September, lengthening to April-November in the 1999 and 2000 seasons (Farlam, unpublished data). Interestingly, this protraction occurred after the tuna farms were moved from inside Boston Bay to the Rabbit Island Tuna Zone in 1998. My Honours research in 2003 revealed that the season had been further lengthened from late March-October (Harrison, 2003). The season increased to encompass January to October in the 2004, 2005 and 2006 breeding seasons and now coincides with the entire length of the SBT farming season.

The breeding season for Silver Gulls is usually over a few months (Smith, 1995) however, it can be lengthened if a predictable food source is available. For example, gulls at Rozelle Bay, near Sydney, breed almost year-round (Smith & Carlile, 1992), those on Penguin Island near Perth, breed for eight months of the year (Meathrel, 1991) and those on Big Island, NSW, breed for seven months of the year. All have an abundant and predictable food source that enables them to breed for this protracted period. The Port Lincoln gulls have lengthened their breeding season over the last 20 years ago to encompass ten months of the year, and this time period reflects and coincides with the development of the SBT farming industry and its season.

The breeding season of the Port Lincoln gulls was longer than that of other populations in South Australia. The usual breeding season in SA is anywhere from July to March, or late August to February (Higgins & Davies, 1996). The populations of gulls used in this study as reference sites each bred for a discrete period over several months, but there was limited synchronisation between sites, suggesting that even though both sites relied on more ‘natural’ foods, the food sources varied and therefore timing of breeding also varied. Whilst Silver Gulls have relatively high fidelity to both the natal colony and breeding colony, some do change breeding colonies (Ottoway *et al.,* 1988; Higgins & Davies, 1996). It is therefore possible that gulls may have been moving between colonies in the Port Lincoln area, however, it is unlikely that Port Lincoln gulls would move to the reference colonies as it is improbable they would move from such a predictable food source. In addition, although Lipson Island is relatively close to the tuna farms, there was no sign of sardine in the diet (Chapter 4), and therefore, it is unlikely that these gulls had bred in the Port Lincoln area previously, as it is doubtful they would switch from such a good quality, predictable food source.

The ten-month breeding season of the Port Lincoln gulls also ensured an increased number of laying peaks, with at least three and possibly four, observed for the Port Lincoln gulls (January, April, July and possibly August), compared to one at Venus Bay and two at Lipson Island. However, it is unknown whether the same pairs re-nest, as this was not tested in this study, although Silver Gulls are known to double brood (Nicholls, 1974). Therefore, the protracted laying season of the Port Lincoln gulls coincides with the SBT season and most likely reflects their major food source, suggesting that breeding gulls have access to an abundant food source for around ten months of the year.

Lengthening the breeding season to ten months is of little benefit if chick survival is low. Gulls with a protracted breeding season can also exhibit a more variable success rate as the season progresses (Nicholls, 1974; Wooller & Dunlop, 1981; Smith & Carlile, 1992; Smith, 1995). At Big Island, where the gulls breed for seven months, very few young survived if hatched more than two months into the season (Smith & Carlile, 1992; Smith, 1995). This is thought to be because the older, more experienced birds breed early in the season, fledging chicks from their one and only brood first brood (Smith, 1995). However, the younger, inexperienced birds breed later with much lower success and may produce up to four clutches within the same season (Smith & Carlile, 1992; Smith, 1995). In contrast to this, the Port Lincoln gulls exhibited similar levels for clutch size and hatching success throughout the season. Although chick survival rate did show evidence of time variance throughout the season, there was no apparent trend and survival was relatively similar as confidence intervals overlapped. Interestingly, in 2005 Lipson Island gulls were only successful with their first nesting peak. Although the survival rate estimates were high for this year, these were only from those eggs that hatched earlier in the season, and did not take into account the eggs that were predated later in the season. This is highlighted in the decreased reproductive output per nest for this year.

The reproductive output of the Port Lincoln gulls remained high throughout the entire breeding season, through all nesting peaks, and this is thought to be one reason the population has increased exponentially over the last eight years. The estimated overall reproductive output (chicks per nest) for the Port Lincoln gulls was ~25-50% larger than that of the reference site gulls for most years of research and although it is acknowledged that some of the parameters used to estimate this were not faultless, it gives an indication of what was occurring.

The Port Lincoln gulls were estimated to be producing between 1.8 and 1.9 chicks per nest and although the survival rates of chicks after 4 weeks and post fledging are unknown for this population, it has been shown to be 56.1% for young birds in their first year of leaving the colony, 63.8% for gulls between one to two years of age and 61.7% for gulls up to three years of age (Smith, 1995). As young birds usually return to the colony between two and three years of age to breed (Ottoway *et al.,* 1988; Smith, 1995), we can apply these statistics to the Port Lincoln data. Therefore survival rate up to breeding age (2-3 years) would be 0.66 (2 years) and 0.41 (3 years) chicks per nest, based on an initial survival rate of 1.85 chicks per nest.

Although there would be a time lag of 2-3 years between juveniles leaving the colony and returning to breed, the population would be increasing at approximately 40-60% per year. There was an increase of 50% a year observed from 1999 to 2000 (Farlam, unpublished data), although this growth rate appeared to reduce from 2000 to 2003. From 2003 to 2005 the rate again exceeded 50% growth, but the population declined in 2006. These differences suggest that there could be a much higher survival rate of young birds up to two years of age in the Port Lincoln area than exhibited in other colonies and that although food may be available, other factors may also affect breeding such as weather and human disturbance. In addition, recruitment of birds from elsewhere could be occurring.

Interestingly, although the estimated overall reproductive output of the Port Lincoln gulls was much higher than that of the reference gulls, not all the reproductive output parameters were larger for this population. Clutch size was always larger for the Port Lincoln gulls however, these results were not statistically significant. There was also no significant difference in the proportion of nests with 1, 2 or 3 eggs between the Port Lincoln and reference sites for the three years of study. For the most part, clutch sizes recorded in this project were greater than those reported from studies done from other states. The mean for the Port Lincoln gulls was at least 2.31 and the reference site gulls was greater than 2.15 during this project, however, the mean clutch size for Venus Bay (~1.8) and the Coorong gulls (1.41) (Harrison, 2003) (may be due to this site being visited once, early in the season) was lower than those reported for other states. These results include mean clutch size of 1.88 for a population in WA (Meathrel, 1991), 2.07 for Big Island near Wollongong and 2.15 for Rozelle Bay near Sydney (Smith & Carlile, 1992).

In contrast to clutch size, the mean egg volume was higher at the reference sites than the breeding sites near the tuna farms, however this was only statistically significant in 2004 and 2005. Some studies suggest that larger eggs produce larger chicks in some gull species (Parsons, 1970; 1972; 1976; Risch & Rohwer, 2000). This is because larger eggs are usually produced by more experienced parents with a more nutritious diet (Bolton, 1991) who lay larger and better provisioned eggs (Verboven *et al.,* 2005). However, as yolk formation is energetically costly to females, when food is short, females may produce eggs that have a small yolk but large albumen, resulting in larger or heavier eggs and chicks but decreased developmental maturity of the hatchling (small yolk) (Mills, 1979; Monaghan & Nager, 1997). This has been observed in gulls that do not have the energy to expend in their eggs (Mills, 1979; Monaghan & Nager, 1997) such as Red-billed Gulls which lay larger eggs to act as insurance to enhance nestling survival when food is scarce (Mills, 1979). Some gulls may also produce smaller eggs with less albumen (same yolk content) to shorten the required incubation period (Parsons, 1972; 1976). This is possibly what was observed for the reference eggs, which were larger, possibly with more albumen, whilst the Port Lincoln eggs were smaller. It is possible that the Port Lincoln eggs may have had a better quality/quantity of yolk as the female parent gulls had access to a food source high in digestible protein, lipid and calcium during the energetically demanding yolk deposition stage. There is also the potential that the Port Lincoln gulls may have had a shorter incubation period than the reference gulls, due to the smaller size of their eggs, though this could not be determined in this study. It is unlikely that the difference in egg volume between sites was a reflection of the difference in age-structure of breeders at each colony as colonies were visited throughout most of the season, so data would have been collected from all agestructures. In addition, whilst there was a significant difference in egg volume between stages of the season, these differences were small (<1cm^3) and there was no consistent pattern of an increase or decrease in egg volume over the year, for the three years of research. Future research could compare yolk content of eggs, ratio of yolk : albumen, or the variation in the rate of yolk deposition in the egg, which may be faster in gulls with access to a high quality food source (as per Meathrel, 1991), a comparison of hatched chick weight to egg volume/or egg composition and a comparison of egg size (and composition) to incubation period. Although the mean egg volume of the Port Lincoln gulls was smaller than the reference gulls, it was still larger than that reported for other Silver Gull populations (Meathrel, 1991). This may indicate that egg volume had little influence on the estimated overall reproductive output of the Silver Gulls in this study, which may suggest the parents were able to compensate for smaller eggs with better access to food during chick rearing.

Mean hatching success was consistently greater for the Port Lincoln gulls than the reference gulls (significant in 2005 and 2006 only). This was reflected by a higher proportion of completely successful nests for the Port Lincoln gulls. Although this is not surprising in terms of food availability, it is when related to the smaller egg size of the Port Lincoln gulls. Some studies suggest that larger eggs have increased hatching success and are more successful in producing chicks in some gull species (Parsons, 1970; 1972; 1976; Risch & Rohwer, 2000). As mentioned above, the smaller eggs of the Port Lincoln gulls may have been better provisioned with yolk (but less albumen), with higher levels of lipid, protein, calcium and sulphonated amino acids than the reference gulls eggs, which may have increased chick fitness and survival.

The hatching success observed in this study was much higher than reported from other studies. Thus, Port Lincoln gulls hatching success was >80% and the reference gulls ranged from 59-78%, compared to 61% hatching success for gulls at Altona (NSW) (Wheeler & Watson, 1963) and 38% on Penguin Island in WA (Meathrel, 1991). Interestingly, there was a decrease in hatching success for the Port Lincoln gulls from 2004 to 2006, which may indicate that as competition increased, tuna feed and/or other food sources may have been harder to find, so gulls spent more time foraging and less time incubating, resulting in a reduced hatching success. There was also a decrease in the hatching of complete clutches for the reference gulls in the 2006 season, which may have been due to low food availability and increased predation (cannibalism) in that year and the fact that Venus Bay was not visited in that year.

Chick survival to fledging was significantly larger in the Port Lincoln gulls than reference gulls in 2004 and 2006, but not 2005. It is unknown why the reference gulls exhibited a larger survival rate during 2005 than the other years, but is likely to be due to the smaller sample size of chicks banded and therefore encountered from this year. Whilst chicks were successfully hatched and reared in the first part of the season, this was not the case in the latter part, as eggs were predated by con-specifics. This is exhibited in the much lower hatching success in the mid and late parts of the season for this year. The survival rate/fledging success exhibited by both populations of birds in this study were much higher than those reported for other population around Australia. Chicks of this age group on Carnac Island near Fremantle, WA, had a fledging success of 49% (Nicholls, 1974), whilst those from Big Island and Rozelle Bay (NSW) were 2.8% and 4.8% respectively (Smith &

Carlile, 1992).

Whilst the Port Lincoln gulls exhibited an increased reproductive output compared to the reference gulls and it seems likely that the aquaculture derived food source is the reason behind this, the diet of the gulls would need to be manipulated experimentally to have conclusive evidence of this mechanism. It can also be hypothesised that this reliable, high quality food source may be contributing to the over winter survival of immatures, non breeding birds and fledglings. Thus, this study has shown that bigger eggs do not necessarily increase chick survival, it suggests therefore that chick rearing has a more important impact on overall chick production and therefore overall reproductive output than egg size.

A diet dominated by fish has been shown to have similar positive effects on other species of gulls where they become reliant on this high quality food source. For a range of gull species, there is a strong positive relationship between the amount of fish taken by pairs and their breeding success, breeding lifespan, total egg production, total hatchling production and lifetime fledging production (Annett & Pierotti, 1989; 1999). This is best shown by Western Gulls that switch to fish on initiation of breeding and have a higher reproductive output than gulls that continue to feed on refuse (Annett & Pierotti, 1989; 1999).

Whilst this study only compared the reproductive output of Port Lincoln gulls to populations eating mainly natural foods, it would be interesting to compare these results (natural and tuna feed) to a population reliant on garbage, such as those at Outer Harbour, as fish and fish derived products have been shown to increase reproductive success in gulls when compared to gulls that only feed on garbage (Annett & Pierotti, 1989; 1999).

In conclusion, it appears the reproductive output and population dynamics of the Port Lincoln Silver Gull population is heavily influenced by the availability of food from the tuna farming industry. This is exhibited in the findings that the breeding season mirrors the tuna farming season (unlike other colonies in the state) and the reproductive output of Port Lincoln gulls was ~25-50% greater than that of the reference gulls.