CHAPTER NINE

GENERAL DISCUSSION AND CONCLUSIONS

9.1 Summary

9.1.1 The Port Lincoln Silver Gull Population

Silver Gull abundance has undoubtedly increased in the Port Lincoln area over the last three decades; a growth which has coincided with the development of the Southern Bluefin Tuna aquaculture industry. The number of nesting pairs on the main breeding colony, Rabbit Island has increased from 100 pairs in 1982 (Farlam, unpublished data) to as high as 19,400 pairs in 2005. Similarly, the maximum number of nesting pairs in the Port Lincoln area has risen from 3,300 in 1999 (Farlam, unpublished data) to as high as 27,800 in 2005. This rapid increase is similar to trends reported for gull species around the world (Furness, 1996; Garthe *et al*., 1996; Belant, 1997; Walter & Becker, 1997; Oro, 1999; Huppop & Wurm, 2000; Bertellotti *et al*., 2001; Martinez-Abrain *et al*., 2002; Yorio & Caille, 2004), and for Silver Gulls in Australia (Smith *et al.*, 1991; Smith, 1992; 1995; Smith & Carlile, 1993; Higgins & Davies, 1996; Temby, 2003; 2004).

Such population increases have been attributed to the gulls' efficient use of anthropogenically created food sources and/or habitats. Human refuse and to a lesser degree, fisheries discards have been the food sources attributed to most of the population increases. However, the dietary analysis (although limited) and city dump abundance results obtained during this project indicate that human refuse is not the main food source for breeding Silver Gull in/around Port Lincoln from January to October. Whilst there were few gulls in the urban areas of Port Lincoln during the tuna season, there were very high numbers at the breeding colonies and at the tuna farms during this time. There were on average 285 Silver Gulls per pontoon per day or feeding event, with an average of ~130 tuna pontoons (Foote, pers. comm.) per season over the three seasons, this equates to 37,000 birds using the farms per day (of which ~25% were feeding). This strongly suggests that tuna feed was a major food source for this species for up to 9 months of the year. However, as the tuna season tapered off, gull abundance rapidly increased at the city dump, with the highest abundance being found from October to January. This annual cyclic pattern that was evident over the three years of research is a mirror image of the tuna farming season and is likely to occur because the gulls must search elsewhere for food in the off season, and thus they frequent the dump and the foreshore. This pattern also reflects the breeding season, but as abundance is low in the town during breeding, most of the gulls are not utilising the town as a source of food.

Interestingly, because the maximum number of gulls observed in the city on one day was ~6,000 it is apparent that only a minor proportion of the entire breeding population utilises the town once the tuna season is over. Furthermore, several adult Silver Gulls that were banded on Sibsey Island in 2003 were observed in Port Lincoln during the off season throughout this project. Similarly, there were sightings in Tumby Bay of fledglings that were banded on Lipson Island.

As the town gull observations were only carried out on two days per month and only seven sites were used, it could be argued that many gulls may have been missed. Whilst perhaps up to 5,000 uncounted birds could be distributed around town during this time, it is unclear where the major proportion of the gull population disperses and this suggests that there is an emigration of birds from the area, with a consequential immigration of birds into the area for breeding. Silver Gulls are known to migrate to and disperse from breeding colonies, sometimes up to 1000km away, upon cessation of breeding, returning to their natal colonies each year (Ottoway *et al.,* 1985; Smith, 1995; Higgins & Davies, 1996). However, these studies also indicate a proportion of the birds are sedentary, remaining close to their breeding sites throughout the year (Ottoway *et al.,* 1985; Smith, 1995; Higgins & Davies, 1996). South Australian studies suggest that juvenile gulls migrate further than adults and the majority of birds stay within 460 km of their colony (Ottoway *et al.,* 1985). The birds that disperse into the city of Port Lincoln could be viewed as sedentary birds (which includes a proportion of the juvenile population), whilst the proportion that disappear could be seen as the migratory birds. But the question remains – where are these birds migrating to? Locations could include summer grain growing areas of the Eyre and Yorke Peninsulas (5-400km), Adelaide (250km) or Lake Eyre (1500km). This requires further research because these migratory gulls may be causing problems elsewhere.

9.1.2 What do Port Lincoln Silver Gulls Eat?

Limited dietary analysis studies have been carried out on Silver Gulls, but they are clearly opportunistic scavengers and eat a variety of food types including organic human refuse and natural food when seasonally available. Natural food of Silver Gulls includes seaweed, terrestrial plants, fruit and seeds, insects, worms, fish, crustaceans, frogs, birds and rodents (Barker & Vestjens, 1989). The principal natural food of laying gulls on Penguin Island, Western Australia is kelpflies, where nesting is timed to their emergence from beach stranding of rotting seagrass (Meathrel, 1991). In contrast, the diet of laying gulls on Big Island, Wollongong consists of both human derived and natural food (Smith *et al.*, 1991; Smith & Carlile, 1993; Smith, 1995). There, 82% of the diet was organic human refuse of which 63% was meat, but they also consumed carbohydrates (e.g. bread, desserts and potato chips), processed seafood, vegetables and some cotton wads. The remaining 18% was food of natural origin which included small fish (Perciformes and clupeoids), crustaceans, squid, insects and worms. Gulls breeding in Hobart were found to rely on human derived food such as potato chips and bread, whilst those breeding on the Furneaux Island Group ate natural food such as berries, insects and crustaceans (Auman *et al.*, 2008). Breeding gulls in Ballarat feed chicks from their first brood a high percentage of earthworms and Coleopteran larvae whilst the second brood is fed human refuse (B. Kentish, pers. comm. in Smith, 1995); whilst the annual reproductive success of Red-billed Gulls in New Zealand is enhanced by the seasonal availability of krill (*Nyctiphanes australis*) (J. Mill unpublished data in Smith, 1995); and gulls that breed at Lake Eyre, South Australia, feed on insects, invertebrates and fish but can predate a large proportion of Banded Stilt (*Cladorynchus leucocephalus*) eggs and chicks (Egan, 1990; Baxter, 2003).

In contrast to the majority of these studies, the diet of breeding Port Lincoln gulls did not consist of mainly human refuse, but more of fish and marine based foods. Although there is limited dietary data suggesting that tuna feed is the major food source of this population (dietary analysis suggests ~20-30%, but notably with sardine only found in the diet of Port Lincoln gulls), the observational data shows that many gulls feed at the tuna farms each day, scavenging the tuna feed. Nevertheless, the diet of the Port Lincoln gulls was significantly different to the other populations used in this study, with leatherjackets being a large part of the Port

Lincoln gulls' diet, whilst grain and parrotfish were more prevalent in the reference site gulls' diet. Whilst leatherjackets naturally occur in the area, they are also one of the most abundant scavengers at tuna farms (the other being sea lice) consuming the majority of the 3% of the feed that falls below the pontoons (Fernandes *et al.*, 2007[b]; Svane & Barnett, 2008) and are a large bycatch of the local prawn trawl industry (Svane, 2005), so it is unclear whether the gulls obtained them through active foraging or scavenging.

Although pellets can be a relatively good indicator of diet, they have their limitations, and this constraint is acknowledged. There is evidence that this method biases towards hard bodied prey (Lindsay and Meathrel, 2008) and the use of otoliths and non-vertebrae bones alone underestimates the consumption of fish with fragile otoliths and indistinct bone structure as otoliths are eroded and damaged, leaving no identifiable features (Votier *et al.,* 2003). Therefore sardines, and possibly other fish which have small otoliths and indistinct bone structure are likely to have been underestimated in the present study. Similarly, readily digested starch based foods and meat (largely scavenged from human refuse) leave no remnants in pellets and are therefore unreported. These reasons can call into question the accuracy of pellet analyses, although it should be remembered that neither human refuse nor different fish bones were identified in chick regurgitations as would be expected were they to be consumed in quantity. It was difficult to collect and analyse the necessary samples to determine diet within the present study but the limited data does suggest this would be of great interest and therefore more research in the form of stomach flushing is required to gain a better understanding of the diet of breeding Port Lincoln gulls, but also of non-breeding birds, to better understand what they eat in the tuna off season.

9.1.3 The Role of Tuna Feed as a Food Source for Seabirds in Port Lincoln

Silver Gulls scavenged tuna feed from pontoons using both feeding methods, but more shovelled feed (2.38%) was scavenged than frozen block feed (1.08%), probably because the shovelled feed was easier to obtain. The extrapolated results from the tuna farm feed loss observations estimate that seabirds consumed ~790 t (1.3%) of tuna feed per annum, with Silver Gulls consuming ~570 t of this. This compares to the Silver Gull abundance data, which suggests that 37,00 gulls were at the tuna farms each day (of which approximately 25% were feeding from the pontoons), which extrapolates to a feed loss amount of ~534 t. However, the dietary analysis approach suggested a smaller amount of ~246 t (28% of the diet). Therefore, the tuna farm observations could have overestimated the amount of tuna feed in the diet of the breeding population, which could have resulted in the low proportion of sardine found in the diet study, although the dietary analysis methodology is likely to be the main influence and the tuna farm observations are likely to be the stronger dataset.

The dietary analysis calculations do not take into account immature birds (1-2/3 year olds) which are an unknown proportion of the population. Although many young may disperse long distances after fledging, some young in the area are sedentary at coastal colonies near suitable habitat (Higgins & Davies, 1996) and may have contributed to the feed loss observed on the tuna farms. This may be another reason the dietary analysis suggested that breeding gulls did not consume the same proportion of tuna feed that was observed on the tuna farms.

9.1.4 Impacts of Tuna Feed on Silver Gull Reproductive Output

Tuna feed represents a high quality food resource to Silver Gulls breeding near Port Lincoln, and this is reflected in the timing of breeding, protracted breeding season, high reproductive output and growth in population. Although this study has shown that clutch size was similar for the Port Lincoln and reference site gulls, and egg volume was larger for the reference gulls, the estimated overall reproductive output per nest of the Port Lincoln gulls was ~25-50% greater than that of the reference gulls, which is exaggerated with the prolonged breeding season with at least three successful nesting peaks in the Port Lincoln area compared to one or perhaps two for the reference site gulls. A similar effect has been reported in other species of gulls, with a high fish content increasing reproductive output, compared to a much lower output for gulls that rely on garbage (Annett & Pierotti, 1989; 1999). This is because fish protein adds to the quantity of protein in egg albumen, and the fat content is incorporated in the yolk, which are both crucial nutritional factors for chick embryos (Wood, 1991).

Although we know that the breeding season of the Port Lincoln gulls runs for ten months, it is unknown whether pairs double brood, as they do in Western Australia over their eight month breeding season due to the long period of food availability (Nicholls, 1974; Wooller & Dunlop, 1979) or whether it is different gulls breeding throughout the nesting peaks. Gulls breeding at Big Island near Wollongong breed for around seven months, with two nesting peaks. The first nesting peak is successful and is assumed to be older more experienced birds, whilst the second peak may be replacement clutches, or inexperienced birds and is relatively unsuccessful (Smith & Carlile, 1992; Smith, 1995). However, unlike the WA birds, although 41% of the

Wollongong pairs nested more than once, they only fledged young from one nesting attempt (Smith *et al.*, 1992). It is thought that double brooding is not a feature of the Big Island colony as it is at carrying capacity, making it difficult to maintain a breeding territory. Thus, the Port Lincoln gulls appear to show a greater similarity to the WA gulls, than the Big Island gulls, with all three nesting peaks of the Port Lincoln gulls being successful. However, in order to answer the questions of whether adults breed more than once per season (double brooding), whether replacement clutches are laid and what proportion of breeders in each laying peak are new birds, it would be necessary to individually band hundreds of gulls and mark nests within different populations.

9.1.5 Minimising Tuna Farm Feed Losses to Seabirds

This study has shown that Silver Gulls in the Port Lincoln area are largely reliant on tuna feed during their breeding season, which has resulted in an over-abundant population. Part of the solution to this problem is to reduce the amount of tuna feed scavenged by the gulls. Over the course of this research, the tuna industry modified their feeding regime from ~50:50 shovel to frozen, to 25:75 which may have been the reason for the decrease in feed loss (and Silver Gull abundance at farms) over the years of this research. In addition, some companies began using scaring devices (such as the float on a rope) during the present study, which may have also contributed to the reductions observed. Shovelled feed loss was significantly higher for companies that shovel fed without a scarer (2.38%) than companies that used a float on a rope scarer whilst feeding (0.34%). This ~86% difference on commercial farms is complemented by the results obtained from the scaring device trial undertaken on a research farm out of season (Dec-Jan) which demonstrated that using a float on a rope whilst shovel feeding could reduce feed loss by up to 87%, whilst the long handled gaff could reduce feed loss by 77%. Whilst the skippers of boats from the two companies that used scaring devices reported using them frequently, there were suggestions from other crew members that they were only used occasionally (and mainly when I was on board). Therefore, these companies may have had a higher feed loss across the season than reported in this study. Nevertheless, a loss of 1.3% (~790 t) of baitfish valued at $630,000 (at an average of $800/t)) to seabirds per annum is enough to warrant the use of scarers on all farms. If we assume that an 86-87% reduction in shovelled feed loss could be achieved if all companies were to consistently use the float on a rope, overall feed loss could be reduced to ~0.8% or 480 t (based on 25:75 ratio of shovel to frozen). This equates to a saving of $246,000, which could be improved if frozen feed loss could also be reduced. This could potentially be achieved through the use of larger baitfish species with less freezer burn and the use of well designed and maintained feed cages.

Future research could involve developing an automated launch and retrieval float on a rope device which could be attached to the pontoon or the boat. This device would be a relatively small change in procedure compared to the efforts that are undertaken to reduce gull scavenging at refuse tips, fishing boats and aquaculture facilities where scavenger management can be time consuming and costly.

In that regard, the efforts undertaken at refuse tips include: the rubbish heap must be compacted and covered in dirt each day to reduce scavenging, wires and nets are erected and acoustic deterrents are used to deter the birds (Collex Waste Management, pers. comm.; Belant & Ickes, 1996; Howard, 2001; Temby, 2003;

Soldatini *et al.*, 2007). The changes made to fishing boats to minimise seabird bycatch and to deter seabirds from scavenging include underwater line setting and hook guards with scaring devices such as streamer lines (Prado, 2001; Lokkeborg & Robertson, 2002). There has also been research undertaken in the use of olfactory deterrents (Pierre & Norden, 2006) and dyeing baits blue to reduce visibility (Cocking *et al.*, 2008). Whereas at the majority of aquaculture facilities, costly exclusion nets are erected as they are the best method of reducing stock predation or feed loss (Price & Nickum, 1995; Glahn *et al.*, 1999; Nemtzov & Olsvig-Whittaker, 2003). These results could be obtained on the SBT farms by completely excluding the gulls from the feed by erecting nets that completely cover the pontoon, as used by local kingfish farms in the area (of the same diameter). This netting would cost between $4,000 and $5,000 for a 40m diameter pontoon (Octoman, pers. comm.). Erecting nets over all pontoons would cost ~$600,000 (120 pontoons x $5,000). This initial cost would be completely recovered the next season, with annual industry savings of $630,000 p.a. The bird-nets have an expected life of 5-6 years, so the benefits of this approach would far outweigh the costs. In addition once the SBT lifecycle has been closed, any companies growing out SBT fingerlings will be forced to net their pontoons to prevent costly stock losses to birds. It is likely that tuna growout will be achieved via a pelleted diet, and it seems possible that once this becomes the norm for one company, more companies may follow suit and therefore netting all growout pontoons may become a better perceived and more feasible option.

9.1.6 Controlling the Silver Gull Population

Whilst a large reduction in feed loss is possible by an industry-wide adoption of float on a rope scaring devices (or potentially exclusion netting) there is still a need to consider direct methods as a quicker means of controlling the over-abundant gull population. Thus, an egg oiling trial was undertaken as part of this project in conjunction with the tuna industry through TBOASA and DEH. The results of this trial, which included a 100% reduction in hatching success, very little re-laying and the majority of gulls continuing to incubate unviable eggs to the estimated hatching date (although there was a higher incidence of early clutch loss than observed for control nests), indicate that this method could significantly reduce the high reproductive output of this population. These findings reflect most results from the literature where egg oiling has been shown to be very successful in reducing hatching success of eggs, however, few have exhibited the outstanding success of this trial.

The results of this trial indicate that oiling Silver Gull eggs could be an effective means of population control. In addition, it is relatively quick and as it is easy to undertake, it does not need highly skilled staff (as long as they can identify Silver Gull eggs from other species). It is also non-toxic to both parent birds and other species and there is no bioaccumulation through the food chain. Due to the success of the trial, TBOASA (under permit from DEH) have undertaken more extensive egg oiling on Rabbit and Louth Islands in 2008 in an effort to reduce the reproductive output of this over-abundant species. Importantly, they are oiling at each nesting peak so that a majority of new eggs are oiled throughout the ten month breeding season. However, further research is required to determine whether the decrease in breeding success has an effect on the population size over the long term and if reproductive output or juvenile and/or adult survival are the key drivers of this population’s growth rate.

Whilst egg oiling proved to be very successful in reducing reproductive output and will largely reduce the population size of the next generation of gulls, it does not manage the extant birds. Culling of adults would reduce this problem, but was not deemed ethical during the breeding season as chicks may have been left to starve. For this method to be ethical as well as effective it would need to be undertaken in the first nesting peak, before any chicks have hatched. Wanless and Langslow (1983) suggest that culling approximately 30% of a gull population annually would hold the population in check. However, Chabrzyk and Coulson (1976) suggest that to be effective, gull control must reduce the density of breeding birds to that level where effectively a new colony has to be formed as it is much more difficult to form or reform a colony than to expand an existing one. This also needs to occur annually and over a wide area, otherwise the high reproductive output of gulls and influx of new recruits ensures the population rapidly increases again (Chabrzyk and Coulson, 1976; Duncan, 1978; Coulson *et al.,* 1982). It is unknown whether a 30% (or 90%) decrease in breeding population would equate to a 30% decrease in scavenging from tuna farms or a 30% decrease in the influx of gulls into Port Lincoln as the full extent of the relationship between these is not clear.

An attempt was made to cull juvenile and adult gulls by gassing with carbon dioxide at the dump by the Port Lincoln Council and TBOASA in early 2008, but this was not very successful as the birds quickly became wary of the trap, which meant very few were caught. It has been suggested that the most effective means of culling a large proportion of the adult population would be the use of alpha chloralose, a narcotic, central nervous system depressant which has been used with varying success in trials or at full scale on Silver Gulls in South Australia (Baxter, 2003), NSW (Smith & Carlile, 1993) and Tasmania (Skira & Wapstra, 1990). However, as this is not a drug listed for this use on gulls, a permit must be acquired from the Federal Government (Australian Pesticides and Veterinary Medicines Authority) to use it for this purpose (Clarke, pers. comm.).

Alpha chloralose is most effective in very hot or cold conditions where it anaesthetises the brain, resulting in hypothermia and death if the dose is sufficient (Baxter, 2003). The most effective regime would involve culling at least 30% of the breeding, adult population using laced bread on the main breeding colony on Rabbit Island (preferably during the first nesting peak or in conjunction with egg oiling), just before sunset with a dose of 100mg of poison per bird (Baxter, 2003). However, care must be taken to ensure that other resident birds such as cormorants, Pacific Gulls, Australian Pelicans and Rock Parrots did not eat the bait.

This regime would ensure gulls would eat the bait, mortality success would be highest and the cull would not be in the public eye. This would need to be an annual event (and in conjunction with a reduction in food availability) otherwise the population would return to pre-cull levels quickly due to the high reproductive output of this population and recruitment from other colonies.

9.1.7 Context of the Study in Ecological and Evolutionary Terms

Silver Gull populations across Australia have expanded over the last century due to the generalist nature of the species. A generalist avian species is defined as one that has non-specific requirements for food or breeding and are generally opportunistic, omnivorous, hardy, mobile, non-specialised, quick breeding, aggressive/competitive risk takers (del Hoyo *et al.*, 1996). In contrast, a specialist species has specific food and habitat requirements (del Hoyo *et al.*, 1996). Generalists can take advantage of and exploit a wide variety of food sources and habitats and are successful under diverse conditions. Generalists not only adapt to humans, they can benefit from their presence through commensal relationships and may be most abundant near human habitation (del Hoyo *et al.*, 1996).

The Silver Gull population in Port Lincoln is yet another example of the adaptability of this generalist species to new niches. Although the Port Lincoln Silver Gull population breeds on offshore islands, a breeding habitat common to this species (Smith, 1995), they have altered their breeding season to mirror that of the season of a major food source. This is exhibited in the protraction of their breeding season, and its variation to that of other populations around South Australia. These gulls have taken a risk to breed over winter, generally a time of less food availability and higher mortality, but this risk has paid off. They have timed their breeding so that they are successful throughout the majority of the breeding season.

The fact that this population has grown substantially over the last three decades also indicates that survival of these birds is also high over summer, even though tuna feed is not available, suggesting seasonal dietary switching. This implies that both the adult and juvenile birds are finding sufficient food over summer to survive until tuna feed is available again. For the proportion of the population that moves to Port Lincoln, this food is likely to include scavenged food from the summer tourist influx into the town as well as human refuse from the dump. However, it is unknown where the remainder of the population migrates to and what they feed on. During the spring/summer influx of gulls into Port Lincoln, the gulls have also been observed scavenging food from dog bowls, pellets from onshore abalone aquaculture farms, consuming insects from cropped fields and lawned areas and eating olives from trees in olive groves (to name a few).

The reason this population, and other populations around Australia have become such a problem is because they are smart, adaptable birds. They are smart enough to know how to exploit a new food source and to breed when this food is available (which can be year round) on nesting habitat which can range from offshore islands to roofs. They are long lived, fairly quick maturing birds with a relatively quick breeding cycle, taking only ~26 days to incubate eggs and 6-7 weeks to fledge chicks (Smith, 1995). These chicks then generally return at around 2-3 years of age to breed (Smith, 1995), but could be maturing and returning earlier with access to this high quality food, which may be worthy of research. They aggressively obtain both food and nesting territory from other birds, often exhibiting klepto-parasitism and can exhibit a relatively large reproductive output. In addition, unsuccessful clutches can be replaced within two re-laying time periods of up to 12 or 76 days (Dunlop, 1986). These characteristics have clearly been observed and advantageous to the Port Lincoln Silver Gull population.

9.1.8 Interactions of Other Seabirds with Tuna Aquaculture

Whilst Silver Gulls were the only seabird researched in detail in the present study, observations of the amount of tuna feed consumed by other species is worthy of mention. This is also particularly important as Silver Gulls are out-competing other species for baitfish at this present time. However, if their numbers decreased due to a cull or egg control, but feed was still readily available, it is likely that other species would increase their consumption of tuna feed.

Crested Terns, which were estimated to have consumed ~134 tonnes of tuna feed per annum (average over three years research) and have increased their consumption of tuna feed since 2003, may be influenced by this food source. Even though Crested Terns in the area breed from around November to March (McLeay, pers. comm.), the tuna feed may be a source of food during breeding from January onwards and it could influence their over winter survival. Although there are few historical data available, this may be the reason that the terns now breed at Donington Island (2007/2008) and have recently started breeding at Dangerous Reef, with around 2000 nests observed at both locations (McLeay, pers. comm.).

Pacific Gulls were estimated to consume an average of ~71 t of tuna feed per annum and Short-tailed Shearwaters ~32 t. It is unlikely that tuna feed is having a major impact on the migratory Short-tailed Shearwater population. About 23 million breed in South-eastern Australia from September to April (DPIWE, 2003) and at the most, only a few thousand were observed at the farms. There may be more of an impact on local Pacific Gull populations, but it is unlikely to affect their reproductive output as they breed from August to December (Armstrong, pers. comm.; Australian Museum, 2008; personal observation), although their abundance in the area is unknown.

Several species of cormorant are abundant in the area and breed anywhere from April to September depending on colony (personal observation; Armstrong, pers. comm.). Being diving birds, they may access the thawing frozen block feed once the feed boat has left the lease, but this could not be monitored and hence their impact is unknown. Non-intrusive observations such as a video camera mounted on the pontoon would be needed to determine how extensive this problem may be. Complete exclusion netting over the pontoon may be required if such studies indicate the amount of frozen block feed scavenged by these diving birds is substantial enough to impact on feed loss, breeding success and over-winter survival.

It is possible that the tuna pontoons are acting as fish aggregating devices (FADs) as large schools of smaller fish are seen in and around the pontoons (personal observation) which may be an attractive foraging site for many seabirds. FADs are known to attract schools of fish, with 15 deployed off the coast of NSW for recreational anglers (Folpp & Lowry, 2006). They have also been shown to attract some seabird species to them due to fish abundance (Jaquemet *et al.*, 2004). This may be the reason that many seabirds such as Skuas, White-faced Storm Petrels, Giant Petrels, Australasian Gannets and cormorants are regularly seen in the lease sites as they do not scavenge tuna feed. The diving birds could catch the scavenger fish that are plentiful below the pontoons which quickly consume the ~3% of tuna feed that is not consumed by the SBT (Fernandes *et al.*, 2007[b]; Svane & Barnett, 2008).

9.2 Future Research

The research described in this thesis provided many insights into the broad scale interactions between Silver Gulls and tuna farms but naturally has also generated many questions for future research.

9.2.1 Foraging Ecology

Whilst Silver Gulls obviously consume tuna feed at the farm sites, and sardines were found in the dietary samples, this study was not able to track individual gulls that scavenged baitfish from a pontoon to a nesting colony. Attempts to track gulls with radio transmitters and GPS trackers were unsuccessful. The radio transponders did not have a long enough range and although the GPS trackers were ordered during the 2006 breeding season, they did not arrive until October 2006, which was too late to use them. Whilst fitting visible leg bands and spending a great deal of time in various places to identify the birds could also produce similar results, I simply did not have the time to sit around and wait to identify birds. It is also extremely hard to identify bands from a moving boat.

Fitting these trackers or satellite trackers to sub-adult and adult birds captured at the nesting colony, at the farms and in the town could help determine the proportion of the breeding and non-breeding population that utilises tuna feed as a food source, and identify other food sources. A relatively small number of trackers (~10) have been used successfully to gain interesting data on foraging ecology in Crested Terns (McLeay, pers. comm.). As the trackers can be retrieved and placed onto new birds throughout the breeding season, they can generate sufficient data to answer a number of questions such as the number of foraging trips per day, foraging patterns variation over the season, individual consistency in foraging destinations, do different parts of the colony differ in foraging patterns, do individual pairs breed more than once and where do the birds migrate after the breeding season? However, a limitation of these GPS trackers is their expense and they have to be retrieved to obtain the data. Therefore tagged birds would need to be dyed so they could be easily sighted and the tags retrieved. Trapping and retrieval would be easier with nesting birds, as their eggs or very young chicks would ensure they return. GPS tags would be inappropriate on non-nesting gulls being monitored on farms or in the town, because they would be extremely difficult to recover, and hence satellite trackers that transmit a signal would guarantee results, although they would also be difficult to retrieve and re-use on other birds to build up a greater number of observations.

This tracking data could be coupled with a dietary analysis of the tracked birds which could involve stomach flushing the bird when the tracker is fitted and again once it is collected, or putting a balance under the nest to weigh the parent gulls when they return from foraging, which would be linked with a remote camera to observe what is being fed to the partner/chick. A larger dietary analysis throughout the colony based on the stomach flushing of about 500 gulls per year would be a valuable insight into their diet because stomach flushing collects freshly consumed items, instead of just the indigestible regurgitated portions found in pellets. Identification of prey items through DNA analysis of pellets, stomach contents or faeces could also be undertaken (Deagle *et al.,* 2007; 2009). The dietary analysis could also be coupled with body condition and blood analysis research (Auman *et al.,* 2008) to monitor cholesterol and other factors that may be influenced by diet to compare gulls that consume tuna feed with those that consume natural food and those that consume scavenged anthropogenic food. Determining foraging patterns would also help determine where parts of the diet such as leatherjackets were obtained and how much of the diet comes from natural foraging or scavenging from fishing boats.

9.2.2 Further Reproductive Output Studies

Interestingly reference site gull eggs were significantly larger than those of the Port Lincoln gulls. Populations of Red-billed Gulls, a sub species of Silver Gull, have also been shown to differ in egg size due to differences in yolk and albumen content which was related to the nutritional status of the parent (Mills, 1979). The hypothesis generated from that study was that because yolk formation is energetically costly compared to albumen deposition, birds with access to a good quality, abundant food source produce smaller eggs with more yolk, whereas gulls that had a less nutritious diet laid larger eggs, having a small yolk, but larger albumen as insurance. This hypothesis could be tested by comparing the yolk content of the Port Lincoln and reference site gull eggs or comparing the rate of yolk deposition in the egg, which may be faster in gulls with access to a better quality food source (Meathrel, 1991).

It would also be worthwhile to analyse the reproductive output and foraging ecology of the other seabirds using tuna farms as a food source. Although they may only breed during part of the tuna season, the tuna feed may influence the fledging success of species such as Crested Terns that fledge chicks during the tuna season and whose natural prey is sardines (McLeay, pers. comm.). The high quality food source may be facilitating immigration into the area and influencing over winter survival and possibly foraging behaviour of these other species.

9.2.3 Other Scaring Devices or Control Measures

Although a simple scaring device has been shown to be effective in reducing feed loss to birds on the tuna farms, there are other devices that could be tested. These include running wires across the pontoons to deter birds swooping (Belant & Ickes, 1996; Temby, 2003) and deploying a net to successfully enclose the entire pontoon which would exclude birds completely (Howell & Munford, 1991; Price & Nickum, 1995; Nemtzov & Olsvig-Whittaker, 2003; Huon Aquaculture, pers. comm.). However, these methods need constructive input from the industry to refine them as at this point in time they perceive them as likely to impede day to day activities. Further research is required on the use of gull distress calls (Soldatini *et al.*, 2007) which TBOASA is currently trialling (Ellis, pers. comm.). Unfortunately, they are using non-native gull calls, which were relatively ineffective at scaring Silver Gulls when used on Yellowtail Kingfish farms (personal observation), but they will be obtaining the distress calls of local gulls which are likely to be more effective and could be coupled with other methods.

Further research into the effectiveness of egg oiling over an entire season and over subsequent years could also be undertaken. DEH and TBOASA are undertaking this as a population control method in the 2008 season, however, the long term effects of this method are unknown. The long term effects of this method need to be researched in order to know whether a reduction in breeding success would in fact reduce the size of this population. The questions also remain as to whether gulls that have consecutive nests oiled migrate to other breeding colonies or do they become more sensitive to oil over time and subsequently re-lay once they detect that the egg has been oiled?

Further research is also required on the efficacy of culling adults of this population with alpha chloralose. This drug is not registered for controlling bird populations in South Australia, although it has been used on a trial basis on Silver Gulls at Lake

Eyre and the lethal dose has been determined (Caithness, 1968; Baxter, 2003), it has not been tested on offshore breeding colonies in this State where other gull species are present.

9.3 Final Conclusion

In conclusion, the tuna aquaculture industry has had a dramatic impact on the Silver Gull population around Port Lincoln through the use of feeding methods that make high quality baitfish readily available to this hugely adaptable, opportunistic scavenger. The quantity and quality of food has caused a rapid population increase through an enhanced reproductive output compared to other colonies. However, the tuna farming industry have responded favourably, marginally reducing feed loss through changes in feeding regime, the use of scaring devices and coordinating and undertaking population control measures. However, these responses, in particular food source management, must be continued, extended and improved to take control of this problem. In essence, this research has been an effective example of scientists working together with industry and regulators to overcome an economic, biological and social problem.