CHAPTER THREE

SEABIRDS SCAVENGING AT TUNA FARMS: FEED LOSSES AND SEABIRD ABUNDANCES

3.1 Introduction

Seabirds naturally forage for food in the intertidal, inshore and offshore areas of the coast, however, human exploitation of living marine resources has provided an increasing opportunity for some species to take advantage of food that would otherwise be unavailable to them and to further exploit resources already in their diet (Serventy *et al*., 1971; Furness *et al*., 1988). Exploiting fisheries and aquaculture activities are thus an extension of some seabirds' natural foraging activities and can supply these populations with an abundant and predictable food source (EIFAC, 1988; Oro *et al.*, 1996; Huppop & Wurm, 2000).

Offshore from Port Lincoln, South Australia, seabirds compete with farmed Southern Bluefin Tuna (SBT) for the baitfish feed from January to October each year. This is unlike most aquaculture-bird interactions where predation of stock is the major problem. Whilst some research has been undertaken on feed losses to birds on overseas farms (EIFAC, 1988; Belant *et al.,* 2000; Harpaz & Clarke, 2006), results were mainly obtained from conversations with the farm managers and not from an observational study based solely on this interaction, and prior to 2003, there had been no research undertaken on this type of interaction in Australia. In 2003, an Honours project was undertaken to observe the interactions between seabirds and the SBT industry, and to quantify tuna feed loss to seabirds (Harrison, 2003). This research was carried out throughout the entire season on one tuna company's farm.

The results indicated that loss of baitfish to seabirds using the shovel method was approximately 5.3%, whereas, there was no feed loss using the frozen block method, however, the losses to diving birds such as cormorants could not be established. This company also used a small proportion of pellets, and lost approximately 1% to scavenging seabirds.

As approximately half of the baitfish was distributed using the shovel method and half in frozen blocks, overall feed loss was estimated at 2.3% which equated to 70t, or $70,000 as baitfish was approximately $1000 a tonne during this year (Harrison, 2003). Seabirds preferred baitfish over pellets, probably because baitfish are similar to the natural food of these seabirds and being lubricated are easier to manipulate and swallow than pellets. However, the industry is unlikely to adopt pellets as a major feed source in the near future, but will continue distributing around 60,000 tonnes of baitfish per annum (Montague, 2006).

Of the tuna feed scavenged by birds, 85% of the baitfish and 55% of the pellet feed was scavenged by the Silver Gull which was also the most abundant species at the pontoons, with an average of 500 birds per pontoon. Pacific Gulls consumed proportionally more pellets (45%) than baitfish (8%) and had an average abundance of 60 per pontoon. Short-tailed Shearwaters and Crested Terns combined consumed around 7% of the baitfish taken and less than 1% of pellets and had an average abundance of about 30 and 10 birds at the pontoons respectively (Harrison, 2003).

The methods used to quantify feed loss in that study were based on direct observations. Seabirds were observed scavenging the feed for a set period of time and the number of pieces of baitfish taken by each species was recorded. For each pontoon the average mass of baitfish was calculated, the mass of baitfish distributed per pontoon obtained and the time or number of shovel loads taken to distribute the feed recorded. All of these details were used to estimate the quantity of feed scavenged per pontoon. Similar methods have been used to quantify stock loss on aquaculture farms and fishery discard consumption rates (Carss, 1993; Glahn *et al.,* 1999; Skov & Durinck, 2001; Barrett *et al.,* 2002; Leukona, 2002; Valeiras, 2003; Hodgens *et al.,* 2004; Svane, 2005; Werner *et al.,* 2005; Werner & Dorr, 2006). These studies have mainly concentrated on quantifying numbers of fish consumed, however, fish species, size and condition can also be obtained, with fish size usually measured as a proportion of the bird's beak. The number of each bird species present is also recorded, as is the length of time present, number of strikes and dives and duration of foraging time. Information from the literature such as the metabolic rate of the bird species can be coupled with availability of discard types, standard feeding rates and diet composition which can be compiled to estimate how many fish were consumed per hour/day/season/year (Carss, 1993; Glahn *et al.,* 1999; Bertelloti & Yorio, 2000; Skov & Durinck, 2001; Barrett *et al.,* 2002; Leukona, 2002; Valeiras, 2003;Hodgens *et al.,* 2004; Svane, 2005; Werner *et al.,* 2005; Werner & Dorr, 2006).

Observational data can have limitations and create highly variable results due to many factors such as difficulty in maintaining observations of birds with different foraging methods, rough weather, large ponds or fast feeding rates making observations difficult, and so many researchers couple real time observations with experiments (Garthe *et al.,* 1996; Glahn *et al.,* 1999; Bertelloti & Yorio, 2000; Glahn *et al.,* 2002; Martinez-Abrain, 2002; Werner *et al.,* 2005). In some cases captive bird experiments alone have been used to estimate feeding rates (Glahn *et al.,* 2002;

Werner, 2004; Werner & Dorr, 2006). These experimental approaches limit the number of birds and controls the quantity of food available so the results are easier to obtain and can be more accurate. Captive bird trials on aquaculture facilities involve placing a known number of wild birds into an enclosed pontoon area with a known quantity of fish and then observing the foraging rates (Glahn *et al.*, 2002; Werner, 2004; Werner & Dorr, 2006). The birds are removed after a certain period of time and the fish in the pond harvested and counted to quantify the number predated. The results generated determine the number or weight of fish predated per bird per day. This information can be compared to the wild bird data to gain a better understanding and possibly a more accurate result (Glahn *et al.*, 2002; Werner & Dorr, 2006). Experimental approaches to estimating discard consumption involves taking known quantities of common discard species from the haul, weighing and measuring them and then dropping them into the water from the boat. The distribution, abundance and feeding behaviour of each seabird species present is monitored to ascertain preference and total consumption (Garthe *et al.*, 1996; Walter & Becker, 1997; Martinez-Abrain, 2002). This type of experiment is also used to determine the behaviour of each discard type upon release (float, sink, swim away) and therefore how long it is accessible to the seabirds (Hill & Wassenberg, 1990).

As the tuna feeding observations were undertaken on offshore, commercial pontoons, it was not appropriate to undertake an experimental approach. Observations of feeding events were used to quantify feed loss and video taping of feeding events was undertaken to assess the accuracy of the observation method.

This chapter aims to build on the baseline data obtained by my Honours project in 2003 (Harrison, 2003) and to investigate these interactions further to quantify feed loss to seabirds and to compare SBT feeding methods in terms of feed loss and seabird abundance.

Aims

The primary aims of this chapter were:

- To assess the accuracy of the technique for quantifying feed loss in real-time.
- To quantify tuna feed loss to Silver Gulls for the industry over several years (using as many companies as possible).
- To compare feed loss between the different feeding methods utilised by the industry.
- To quantify tuna feed loss to other seabirds.
- To assess if seabirds have any preference for different baitfish species.
- To compare seabird abundance at different tuna farms utilising different feeding methods.
- To find an industry best practice feeding method in terms of reducing feed loss to seabirds.

Hypotheses

H0: There will be no difference in feed loss quantified using real time observations and videoed events.

HA: There will be a difference in feed loss quantified using real time observations and videoed events.

H0: The method used to distribute tuna feed will have no effect on feed loss to seabirds.

HA: The feed distribution method will have an impact on the amount of feed scavenged by seabirds.

H0: Frozen block feed cage design will have no impact on feed loss to seabirds.

HA: There will be a change in feed loss for the different feed cage design (poorly designed or maintained frozen feed cages vs. well designed or maintained cages.

H0: The baitfish species fed to the tuna will have no impact on feed loss to seabirds.

HA: The baitfish species used will have an impact on feed loss results.

H0: There will be no difference in the amount of feed consumed by each of the seabird species present at tuna farms.

HA: Different seabird species will consume different amounts of baitfish.

H0: There will be no difference in abundance of all the seabird species present at the farms.

HA: Different seabird species will be present in different abundances at the tuna farms.

3.2 Methods

3.2.1 Tuna Farm Feed Loss

3.2.1.1 Study Area

This research was undertaken over the 2004, 2005 and 2006 tuna farming seasons on commercial tuna farms (See Figures 2.3-2.6 for lease sites). Eight out of the 13 companies that farm tuna were used in this project. Some companies were used two or three years in a row, whilst some were only used for one year.

During the 2004 season, four companies' feeding practices were observed. Each lease was visited over one to two days, with two to seven feeding events observed per visit. During the 2005 season, four companies' feeding practices were observed with each lease visited over one to four days, with two to ten feeding events observed per visit. During the 2006 season, seven companies' feeding practices were observed with each lease visited for one day, with three to fifteen feeding events observed each visit.

3.2.1.2 Feeding Methods

Two main methods (shovel feeding and frozen block feeding) were utilised to distribute the baitfish feed on the SBT farms, however siphoning was used occasionally (§Chapter 2.2.1). Approximately half of the feed was distributed using the shovel method, and the other half using the frozen block method in the 2003 and 2004 seasons, however this had changed to a ratio of 25:75 in the 2005 and 2006 seasons. Two companies used some form of scarer whilst shovel feeding which mainly included a float on a rope (§5.2.2 for a full description).

Companies that used frozen block feeding were broadly divided into two categories; 1. Well designed and maintained feed cages (Figure 3.1) and 2. Poorly designed and maintained feed cages (Figure 3.2). Each company was categorised on the shape and condition of the feed cage above the surface. Feed cages were not assessed on each visit, but a general classification was given for the condition of the feed cage over the season. A well designed feed cage usually had a triangular shaped lid with well maintained mesh (Figure 3.1), whilst a poorly designed cage would usually have a flat lid, or soft netting which allowed access to the food within the cage (Figure 3.2). A poorly maintained cage would usually have a broken lid or holes in the mesh which would allow access to the food. This could also cause entrapment and subsequent death of seabirds within the feed cage.

Figure 3.1: A well designed and maintained feed cage.

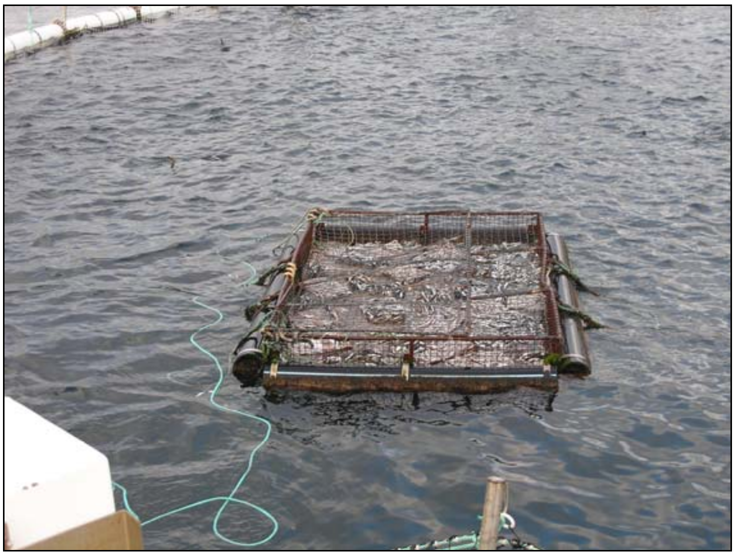

Figure 3.2: A poorly designed and maintained feed cage.

3.2.1.3 Observations

Two types of observations were made on the tuna farms.

1. The number of individual pieces of feed consumed by seabirds per set period (per shovel load or per minute) and
2. the abundance of each species of seabird present at the farms.

Seabird Numbers

Seabird numbers were estimated by direct counting or estimation (§Chapter 2.3 for a detailed explanation).

Seabirds were classified into two categories and positions around the pontoon.

1. Inside and above the pontoon.
2. Outside the pontoon.

Both numbers were also combined to determine total abundance of that seabird species at each tuna pontoon.

Amount of Feed Consumed by Seabirds

The estimation of the amount of feed consumed by seabirds for the different feed methods is described in Chapter 2.2.

3.2.1.4 Calibration of Feed Loss Data

Real-time observational feed loss data were calibrated by independently recorded video analysis of the same feeding event. This calibration was done with help from TBOASA, who provided a technician (Danielle Foote or Teau Tenamau) who filmed shovel and block feeding during the 2006 season. The videotaping took place at the same time as real-time observations. These tapes were then viewed at a later date by Danielle and I, and were slowed down if necessary to count the pieces of fish scavenged from the farm during the feeding events. The 'calibrated' data were then compared to the observed 'real-time' feed loss data and the accuracy of the 'real-time' method assessed. It was not possible to video tape any siphon feeding due to its minimal use as a feed method.

3.2.1.5 Data Analysis

An SPSS Bland Altman Analysis was used to compare the level of agreement between the two measurements ('real-time' and 'calibrated') for estimating the amount of feed scavenged by seabirds (Bland & Altman, 1986).

One Way ANOVAs were used to analyse for differences in feed loss to scavenging birds for the different feeding methods, feed cage design, baitfish size class and baitfish species. Feed loss percentages were transformed in SPSS using the arcsin transformation to improve data normality. It was not possible to compare these variables (feeding method, feed cage design and baitfish species) within a Two Way ANOVA as there were already too many other variables to factor in (pontoon number, company, year) which did not allow analysis to proceed.

A Two Way ANOVA was used to test for differences in feed loss between feeding methods and years.

The Test of Proportions in Microsoft Excel was used to test for differences in the proportion of baitfish species consumed by each seabird species. This test is used to compare two proportions using the observed sample proportion (p) and the sample size of the proportion (n). The formulas 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 of Moore & McCabe (2006) for further information.

Two Way ANOVAs (SPSS) were used to test for differences in Silver Gull abundance (natural logarithm transformation) and Crested Tern abundance in two locations (inside and outside the pontoon) for different feeding methods. Separate One Way ANOVAs (SPSS) were performed to explore abundance differences for different feeding methods at individual locations (inside or outside). Pacific Gull and Short-tailed Shearwater abundance could not be analysed as there were too many zeros in the dataset.

In all tables N equals the total number of feeding events observed.

Due to constraints on my research (§Chapter 1.9), some of the data could not be analysed statistically due to its 'complexity'. This complexity relates to the following issues: (1). I usually had more than one observation for a pontoon per year, (2). I could not always use the same company's pontoons over consecutive years, (3). the 8 companies were not uniform in terms of feeding regime, location of lease relative to land, and attitude towards environmental matters and (4). to normalise the data I had to combine all three years together. This meant that I had to average data from the same pontoon (within a company), nest pontoons within a company, and then nest pontoons within each company within each year. When there were several other variables to consider such as feeding method or several seabird species, it was sometimes not possible to carry out the analysis (a decision which was made after thorough discussion with a statistical consultant and exhausting all possible avenues). This 'complexity' is illustrated in Table 3.1. This table lists all the variables which had to be taken into account to quantify feed loss in the 2005 season.

Table 3.1: Sampling matrix showing the independent variables for observations of tuna feed consumed by seabirds (dependent variable) in the 2005 season. Seabird species was not included but is also a variable. Each row is an observation.

Year	Company	Feed Method	Pontoon number	Baitfish Species	Baitfish Size	Scarer Used	Design & Maintenance
2005	Company A (n=28)	Shovel (n=9)	2	Red	Med	No	N/A
			4	Red	Med		
			6	Cal Red	Med Med		
			7	Red	Med		
			8	Cal Red	Med Med		
			9	Red Red	Med Med		
		Frozen (n=19)	1	Mix Mix Red	Med Med Med	N/A	Good
			2	Mix	Med		
			3	Mix	Med		
			4	Mix	Med		
			5	Mix Mix	Med Med		
			6	Mix Mix Red Mo	Med Med Med Med		
			7	Red	Med		
			8	Mix Mix Red	Med Med Med		
			9	Mix Mix Red	Med Med Med		
	Company D (n=6)	Shovel only	1	SA	Small	Yes	N/A
			2	SA	Small		
			3	SA	Small		
			4	Mix	Med		
			5	Mix	Med		
			6	Mix	Med		
	Company G (n=22)	Frozen only	1	SA Red SA	Small Med Small	N/A	Good
			2	SA Red SA	Small Med Small		
			3	SA Red Cal	Small Med Med		
			4	SA	Small		

				SA	Small		
			5	SA Red Cal	Small Med Med		
			6	Red SA	Med Small		
			7	Mo Cal	Med Med		
			8	Mo	Med		
			9	Mo	Med		
			10	Red Red	Med Med		
	Company H (n=20)	Frozen only	11	SA	Small	N/A	Poor
			12	SA	Small		
			13	SA Anch	Small Small		
			14	SA	Small		
			15	SA	Small		
			16	Anch	Small		
			17	Anch	Small		
			18	Anch	Small		
			19	Anch	Small		
			20	Anch Anch	Small Small		
			21	Red Anch	Med Small		
			22	Red Anch Red	Med Small Med		
			23	Red Anch Red	Med Small Med		

Note: Baitfish species – Red = Redbait, Cal = Californian Sardine, Mix = mixed baitfish, Mo = Moroccan Sardine, SA = SA Sardine, Anch = Anchovy; Baitfish size – Small, Med = Medium) (See Table 3.7 for a full description).

3.3 Results

3.3.1 Feed Loss Calibration

'Real time' tuna farm feed loss results were compared with results taken from video of the same feeding events to assess the similarity between the two (Figure 3.3).

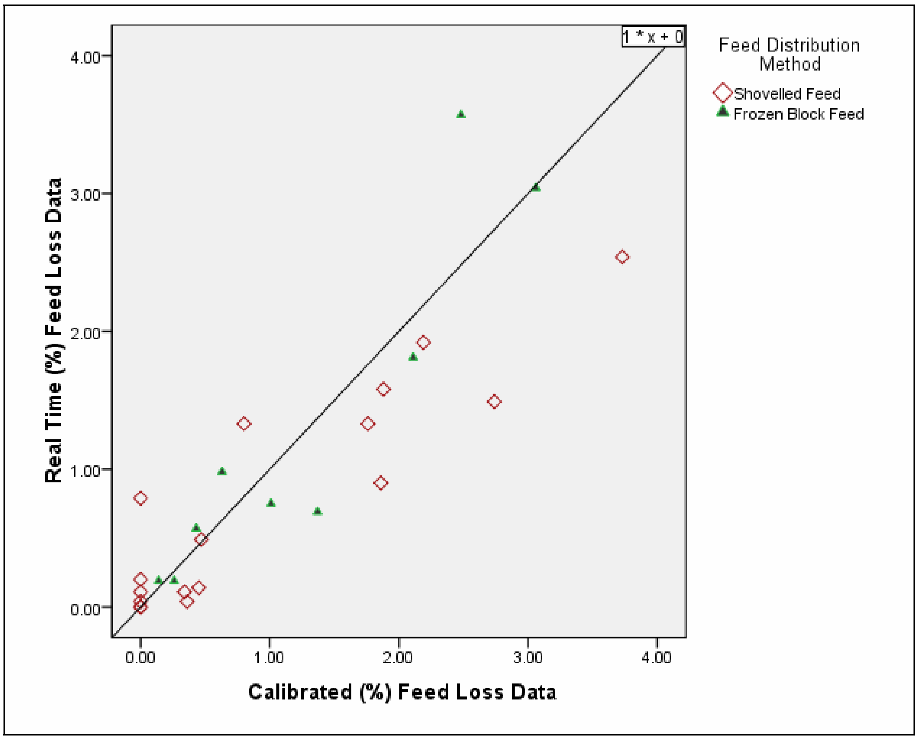

Figure 3.3: A scatterplot of real time feed loss data vs. video taped feed loss data points for both the shovel feeding method (red diamonds) and the frozen block feeding method (green triangles). Data are percent of the total tuna feed distributed that is consumed by seabirds. Data generally follow the 1:1 line, although as feed loss increases, the data deviate slightly from the line.

3.3.1.1 Shovelled Feed

A Bland Altman Analysis was used to assess how similar the results were for the 'real time' and 'video calibrated' percentage shovel feed loss data. The analysis showed that when feed loss was small (0-0.5%), the real time method was quite accurate, with most of the difference in the data range being close to 0. However, when feed loss was larger, the amount lost was generally underestimated by the 'real time' observer. Overall, the real time feed loss method for shovel feeding underestimated actual feed loss by an average of 0.21% (Table 3.2) with a maximum overestimation of 0.79% and a maximum underestimation of -1.25%. Percentage differences are absolute, not proportional differences.

This means that there was an average error of around 10%, which could be as high as 50%, of the amount scavenged which was probably due to factors such as weather conditions, field of view, shovel loads chosen and the speed and abundance of scavenging birds. Figure 3.4 shows the limits of agreement for this analysis and indicates that feed loss calculated using this method will be within -1.34 to 0.76% of the actual loss.

Table 3.2: A comparison of the real time feed loss data to the calibrated data.

Shovel Feed Loss Calibration	
Real Time Mean	0.765
Calibrated Mean	0.975
Mean Difference	-0.21
Difference Standard Deviation	0.542
Maximum Difference	0.79
Minimum Difference	-1.25
N	17

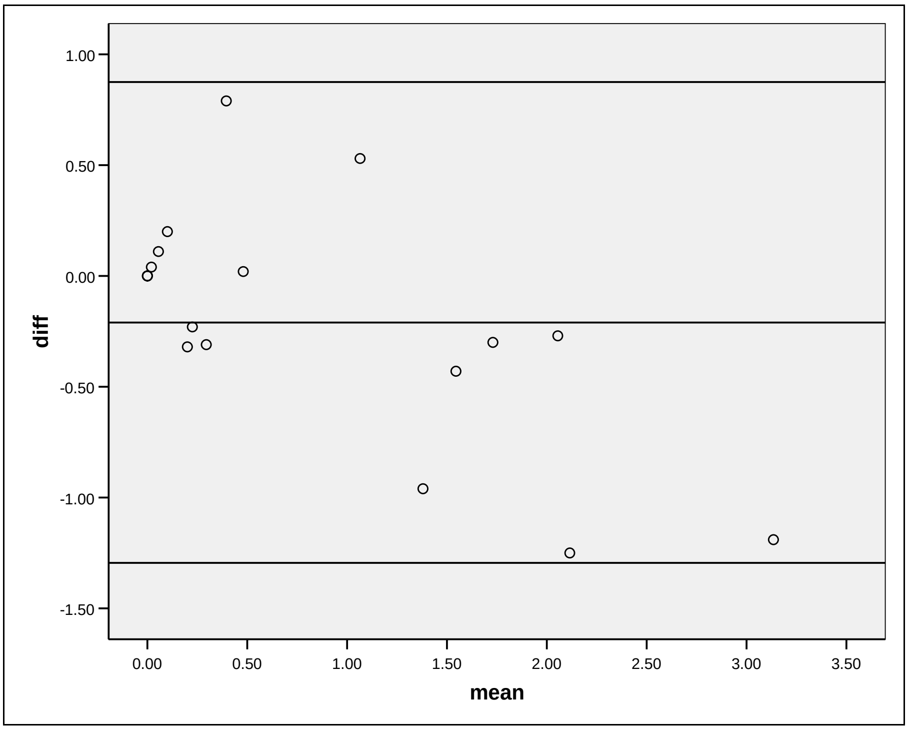

Figure 3.4: Bland Altman Analysis showing the mean versus the difference between the two means (real time and video calibrated shovel percentage feed loss). (Outer lines=limits of agreement (maximum and minimum difference), middle line=average difference)).

3.3.1.2 Frozen Block Feed

A Bland Altman Analysis was also used to assess how similar the results were for the ‘real time’ and ‘video calibrated’ observational frozen block percentage feed loss data. The analysis showed that when feed loss was small (0-0.75%), the real time method was quite accurate, with most of the difference in the data range being close to 0. However, when feed loss was larger, the amount lost was generally overestimated by the ‘real time’ observer, although there were few data points in this range. Overall, the real time feed loss method for frozen block feeding overestimated actual feed loss by 0.03% (Table 3.3), with a maximum overestimation of 1.09% and a maximum underestimation of -0.68%. Figure 3.5 shows the limits of agreement for this analysis and indicates that feed loss calculated using this method will be within -0.95 to 1.02% of the actual loss. Percentage differences are absolute not proportional differences.

Whilst the average difference was not large, the range in differences was, which may be due to the small sample size, but suggests the error may be as large as 100% in some cases for this method. This may be due to the factors such as weather conditions, field of view and possibly birds being more likely to drop partially frozen fish, rather than fresh fish (shovel method), which would not necessarily be picked up by a real time observer.

Table 3.3: A comparison of the real time feed loss data to the calibrated data.

Frozen Block Feed Loss Calibration	
Real Time Mean	1.310
Calibrated Mean	1.277
Mean Difference	0.033
Difference Standard Deviation	0.493
Maximum Difference	1.09
Minimum Difference	-0.68
N	9

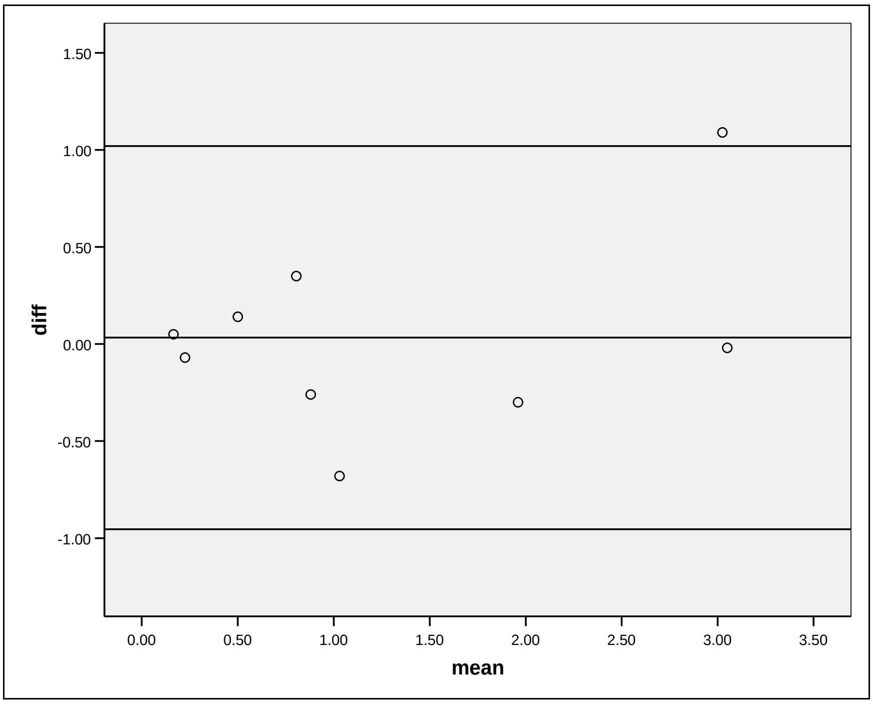

Figure 3.5: Bland Altman Analysis showing the mean versus the difference between the two means (real time and video calibrated shovel percentage feed loss). (Outer lines=limits of agreement (maximum and minimum difference), middle line=average difference)).

3.3.2 Feed Loss to Scavenging Birds

3.3.2.1 Feed Distribution Method Comparisons

There was a significant difference in feed loss to seabirds between feed distribution methods (One Way ANOVA: (Brown-Forsythe) $F_{3, 82} = 10.3$, $p < 0.0001$) (Table 3.4). Feed loss was highest using the shovel method with no scarer, and lowest both using the siphon method and shovel with a scarer. Post hoc comparisons using the Tukey HSD method found that these differences were between shovel feeding without a scarer and shovel feeding with a scarer ($p<0.0001$), shovel feeding (no scarer) and frozen block ($p=0.023$), shovel feeding (no scarer) and siphon feeding ($p=0.047$), and shovel feeding (scarer) and frozen block ($p=0.017$). However, there was no significant difference between shovel feeding (scarer) and siphon feeding ($p=1.0$) and frozen block feeding and siphon feeding ($p=0.436$).

Table 3.4: Feed loss comparisons (% baitfish lost to seabirds) for different feeding methods. Values that are not significantly different to each other share a superscript ($p>0.05$).

	Shovel		Frozen	Siphon
	No Scarer	Scarer Used		
Mean	2.38	0.34^{*}	1.08^{+}	0.31^{*+}
Standard Deviation	2.85	0.48	1.07	0.32
Range	0-11.58	0-1.57	0-4.61	0-0.66
N	48	27	106	6

Shovel Feed: Individual Companies Year by Year

It is evident from Figure 3.6 that shovel feed loss was very different between companies and between years, however, due to the complexity of the data set (as described in Chapter 1 and 3.2.1.5), the data could not be analysed statistically. From the graph we can see that company A and B lost substantially more feed than the other companies, however, for company A, this amount decreased for each year of research.

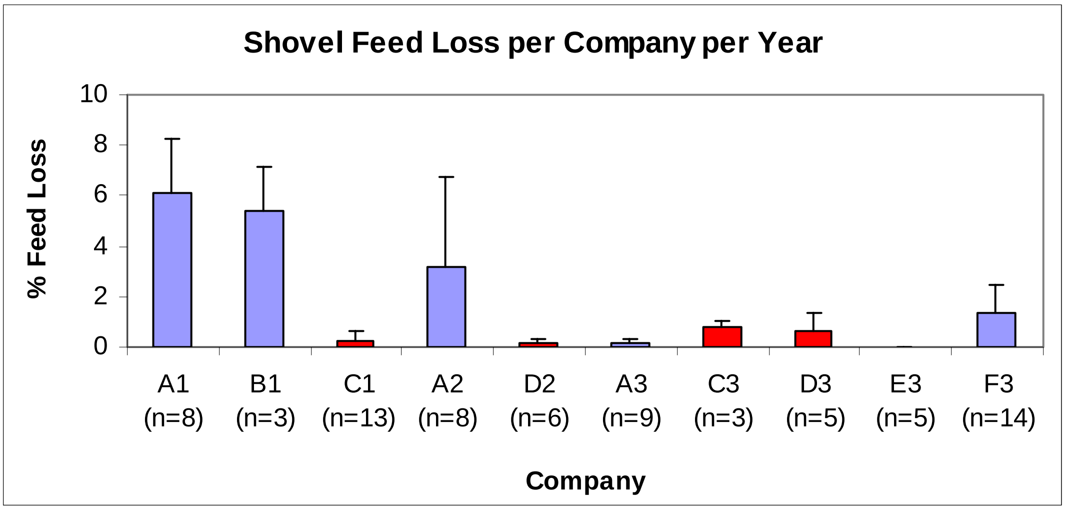

Figure 3.6: Shovel feed loss (%) for each company per year. Each letter represents a different company and the numbers 1-3 indicate years 2004-2006. Blue indicates no scarer used and red indicates scarer used. Error bars=standard deviation. Units = pontoons observed.

Frozen Block Feed: Individual Companies Year by Year

It is evident from Figure 3.7 that feed loss using frozen block feed was highly variable, even when taking feed cage design into account. However, due to the complexity of the data set, this was unable to be analysed statistically. From the graph we can see that companies B and H lost more feed than the other companies for most years. However, company G, whose main feed method was frozen block, showed a substantial increase in feed loss from 2004 and 2005 to 2006.

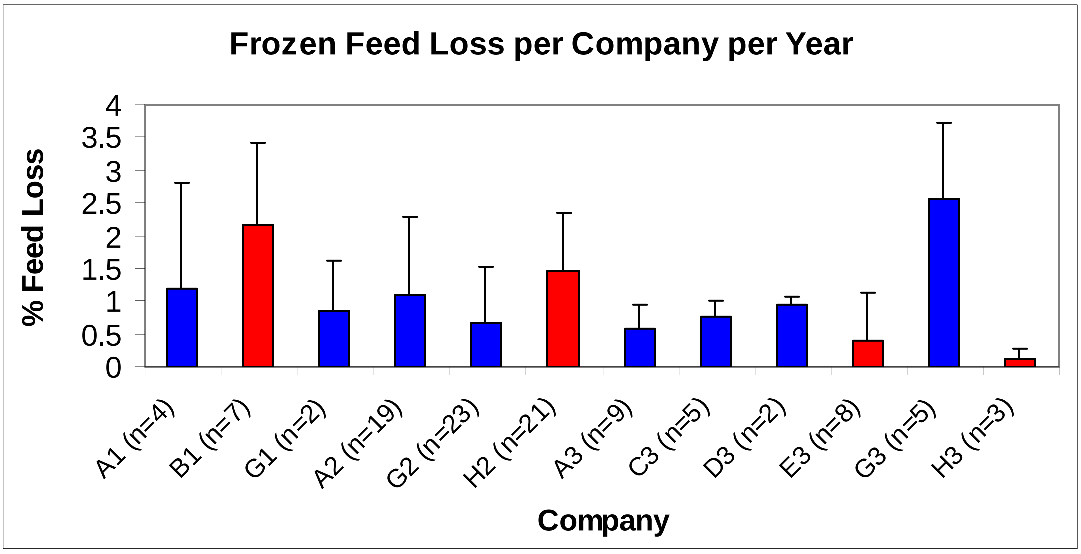

Figure 3.7: Frozen block feed loss (%) for each company per year. Each letter represents a different company and the numbers 1-3 indicate years 2004-2006. Blue indicates that the company generally had well designed or maintained feed cages, red indicates generally badly designed or maintained feed cages. Error bars=standard deviation. Units = pontoons observed.

Frozen Feed: Cage Design

Well Designed vs Poorly Designed or Maintained Cages

Poorly designed or maintained cages lost slightly more feed on average than well designed or maintained cages, however, this difference was not significant (One Way ANOVA: $F_{1, 104} = 2.04$, $p = 0.156$) (Table 3.5).

Table 3.5: Comparison of % frozen feed loss to seabirds for well designed or maintained (good) and poorly designed or maintained cages (poor).

	Good Cages	**Poor Cages**
Mean	0.97	1.27
Standard Deviation	1.05	1.08
Range	0-3.7	0-4.6
N	67	39

All Feed Methods: Year by Year Comparison

There was a significant difference in feed loss between feed methods and years (Two Way ANOVA: $F_{2, 76} = 9.45$, $p<0.0001$). However, because of the unbalanced nature of the dataset, valid post hoc comparisons could not be undertaken, so it is unclear from this analysis where the significantly different values occurred.

It is clear from Figure 3.8 that feed loss for the shovel method (no scarer) decreased substantially for each year of research from 5.9% in 2004 to 0.73% in 2006. Feed loss for the frozen block method also decreased about 0.5% each year (absolute difference). Feed loss for the shovel method with a scarer was slightly higher in 2006 than 2004 and 2005.

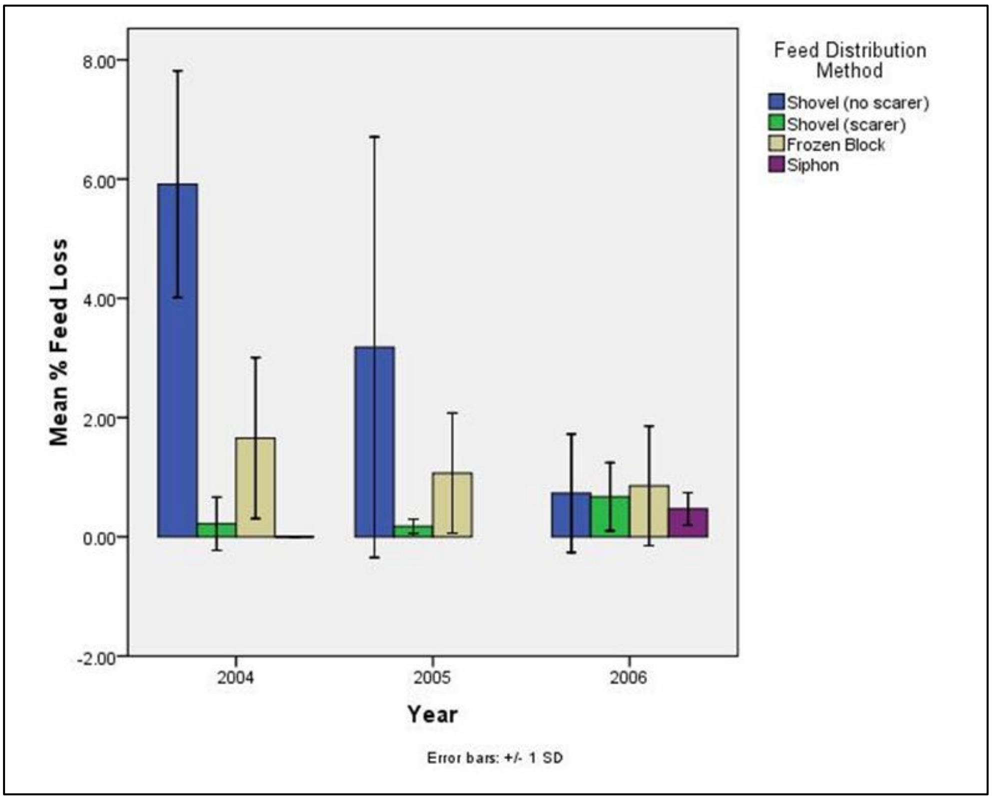

Figure 3.8: A comparison of feed loss between feed methods each year. Shovel (no scarer) n (pontoons): 2004=11 (2 companies), 2005=9 (1 company), 2006=28 (3 companies); shovel (scarer) n: 2004=13 (1 company), 2005=6 (1 company), 2006=8 (2 companies); Frozen n: 2004=13 (3 companies), 2005=63 (3 companies), 2006=30 (6 companies).

3.3.2.2 Individual Seabird Species Scavenging Rates

Silver Gulls were the main cause of feed loss for each of the feed method consuming 72% (of the total feed scavenged) of the shovelled feed with no scarer, 68% of shovelled feed with a scarer and 69% of the frozen block feed (Figure 3.9, Table 3.6). Crested Terns were the next largest consumer of shovelled baitfish (15% no scarer, 8% scarer), closely followed by Pacific Gulls (11% no scarer, 24% scarer), with a very small proportion consumed by Short-tailed Shearwaters (2% no scarer, 0% scarer). Crested Terns were also the second largest consumer of frozen block feed (19%) whilst Pacific Gulls and Short-tailed Shearwaters consumed a small amount of frozen feed (6%).

Silver Gulls consumed significantly more shovelled feed without a scarer than Crested Terns (Excel Test of Proportions: $p<0.0001$), Pacific Gulls ($p<0.0001$) and Short-tailed Shearwaters ($p<0.0001$). They also consumed significantly more shovelled feed with a scarer (mean=68%) than the other three bird species (Crested Terns: $p<0.0001$; Pacific Gulls: $p<0.0001$ and Short-tailed Shearwaters: $p<0.0001$), and significantly more frozen block feed (mean 69%) than the other species (Crested Terns: $p<0.0001$; Pacific Gulls: $p<0.0001$ and Short-tailed Shearwater: $p<0.0001$) (Figure 3.9, Table 3.6).

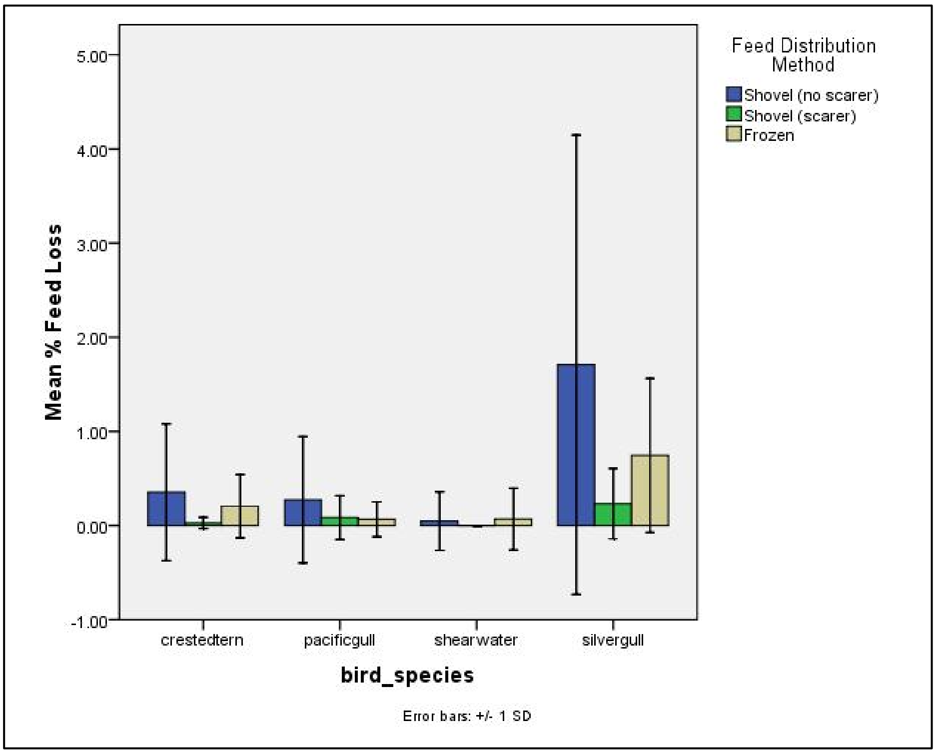

Figure 3.9: Shovel feed loss (% of total feed) scavenged by individual bird species.

Table 3.6: Percent feed loss (% of total feed, and as a % of feed scavenged by seabirds) scavenged by individual bird species (SG=Silver Gull; CT=Crested Tern; PG=Pacific Gull; SH=Short-tailed Shearwater).

	Shovel (No scarer)		**Shovel (Scarer)**		**Frozen**	
	Actual Mean Loss (%)	Proportional Loss (%)	Actual Mean Loss (%)	Proportional Loss (%)	Actual Mean Loss (%)	Proportional Loss (%)
SG	1.71	72	0.23	68	0.74	69
CT	0.35	15	0.026	8	0.2	19
PG	0.27	11	0.083	24	0.07	6
SH	0.046	2	0	0	0.07	6

3.3.2.3 Baitfish Size Class and Species Loss Rate

Table 3.7: Baitfish species description.

Baitfish Type	Average Weight (g)	Average Length (cm)	Description	Size Class
SA Sardine (*Sardinops neopilchardus*)	30	16.5	Locally caught sardine. Slimy exterior.	Small (<50g)
Moroccan Sardine (*Sardina pilchardus*)	90	21	Medium to large imported sardine. Slimy exterior.	Medium (50-100g)
Australian Redbait (*Emmelichthys nitudus nitudus*)	80	22	Medium sized Australian caught species with rough exterior.	Medium (50-100g)
Californian/ Indonesian Sardine (*Sardinops sagax, Sardinella lemuru*)	55	19	2 different species (combined for sample size). Medium sized imported sardines. Slimy exterior.	Medium (50-100g)
Herring (*Clupea harengus, Etrumeus teres*)	135	25	Large imported species. Slimy exterior.	Large (>100g)
Anchovy (local and imported) (*Engraulis*	25	16	Small locally caught or imported species. Slimy	Small (<50g)

australis, Engraulis japonicus, Engraulis mordax)			exterior.	
Mackerel (*Scomber australasicus, Scomber scombrus, Scomber japonicus*)	120	24	Large local or imported species. Roughish exterior.	Large (>100g)

Shovelled Baitfish – No Scarer

Feed loss using this method was highly variable between companies, but also for the six different species baitfish of fed out. A significant difference in feed loss was found for different baitfish size classes using this feed method (One Way ANOVA (Brown-Forsythe): $F_{2, 38} = 11.19$, $p< 0.0001$). The significant differences identified from Tukey HSD post hoc comparisons were between the small and large size class (p=0.026) and the medium and large size class (p=0.010). No significant difference was found between the small and medium size class (p=0.980).

A significant difference in feed loss was also found for different baitfish species (One Way ANOVA (Brown-Forsythe): $F_{5, 19} = 8.07$, $p< 0.0001$) (Table 3.7). The significant differences identified from Tukey HSD post hoc comparisons were between SA sardine and herring (p=0.025), redbait and herring (p=0.033), Californian/Indonesian sardine and herring (p=0.002), and a very weak difference between Moroccan and Californian/Indonesian sardine (p=0.054).

Small sardine species such as Californian/Indonesian and South Australian sardines were the baitfish species consumed in the highest proportion (>5%), although sample sizes were very low (Table 3.7). Larger species such as Moroccan sardine and Australian redbait were still consumed in quite high proportions (>2.5%), whilst the very small anchovy species (both local and imported combined) were consumed in smaller proportions. The very large and bulky herring were consumed in the smallest proportion.

Shovelled Baitfish – Scarer Used

Feed loss using this method was very low and no significant difference was found in feed loss for different baitfish size classes (One Way ANOVA (Brown-Forsythe): $F_{1, 24} = 0.30$, p= 0.590) or baitfish species (One Way ANOVA: $F_{3, 23} = 0.96$, p= 0.429) (Table 3.8).

Frozen Block Baitfish

Feed loss using this method was generally lower and less variable than shovelled baitfish without a scarer. There was no significant difference in feed loss for the different baitfish size classes (One Way ANOVA (Brown-Forsythe): $F_{2, 4} = 2.39$, p= 0.205) or baitfish species fed out (One Way ANOVA: $F_{6, 99} = 1.74$, p= 0.119) (Table 3.8). Although, anchovy and mixed baitfish (imported) were consumed in the highest amount (>1%) which was possibly due to size of the fish and floatability (freezer burn), although there are no data to support this. South Australian sardine, Australian redbait and Californian sardine closely followed these other species, whilst Moroccan sardine was not consumed at all (although sample size of one).

Siphoned Baitfish

Although the data for this feed method could not be analysed as the sample size was only six, it does show that South Australian sardine was consumed in quite small proportions, similar to baitfish shovelled whilst a scarer was used, whilst Moroccan sardine was not scavenged at all using this method (Table 3.8).

Table 3.8: Percentage feed loss comparisons (as a % of total fish fed out) for each baitfish species.

	Baitfish Species	**Mean**	**Std Dev**	**Range**	**N**
Shovel Feed (No Scarer)	SA Sardine	5.88	1.20	5.03-6.72	2
	Moroccan Sardine	2.54	3.53	0-10.29	15
	Australian Redbait	2.71	1.75	0-5.16	11
	Californian/Indo Sardine	7.01	3.96	4.47-11.58	3
	Herring	0.15	0.15	0-0.49	9
	Anchovy	1.52	0.58	0.79-2.54	8
Shovel Feed (Scarer Used)	SA Sardine	0.31	0.32	0-1.07	12
	Moroccan Sardine	0.53	0.67	0-1.57	10
	Australian Redbait	0	0	0	2
	Mixed (mackerel, imported sardine, herring)	0.09	0.06	0.06-0.16	3
Frozen Feed	SA Sardine	0.87	0.51	0-1.85	20
	Moroccan Sardine	0	0	0	1
	Australian Redbait	0.99	1.04	0-3.50	20
	Californian Sardine	0.93	1.09	0-3.57	25
	Anchovy	1.55	1.05	0.11-3.57	16
	Mixed (mackerel, imported sardine, herring)	1.21	1.36	0-4.61	24
Siphon	SA Sardine	0.47	0.27	0.08-0.66	4
	Moroccan Sardine	0	0	0	2

3.3.3 Seabird Abundance at Tuna Farms

3.3.3.1 Total Silver Gull Abundance

The average Silver Gull abundance at each tuna pontoon per feeding event was 285 birds (Table 3.9). This mean increased from 2004 to 2005, but decreased slightly in the 2006 season. There was a significant difference between years (One Way ANOVA (Brown-Forsythe): $F_{2, 158}$ =6.7, p=0.002). Tukey post hoc comparisons showed this significance was between 2004 and 2005 (p=0.052) and 2004 and 2006 (p=0.001), but not between 2005 and 2006 (p=0.278).

This result can be used to extrapolate the total number of Silver Gulls utilising the tuna farming industry as a food source per day.

Mean number of gulls per pontoon (285)* average number of pontoons over the three years (130 (Foote, pers. comm.)) = 37, 050 ± 3,209 (standard error) Silver Gulls per day/feeding event.

Table 3.9: Total Silver Gull abundance at tuna pontoons for all years combined and for each year individually.

	Mean for 3 years	2004	2005	2006
Mean	285	143	333	310
Std Dev	337.5	141.3	425.3	281.9
Range	3-1704	13-620	3-1704	34-1180
N	187	39	78	70

Feed Method Comparisons

There was a significant difference in total Silver Gull abundance at tuna pontoons for the different feed methods (Two Way ANOVA: $F_{3, 251}$ =4.4, p=0.005). Abundance was highest for siphon feeding and lowest for shovel feeding with a scarer, but was intermediate and very similar for frozen block and shovel feeding (no scarer) (Table 3.10). Post hoc comparisons using the Tukey HSD method showed these differences to be between abundance at shovel fed pontoons (with a scarer) versus all other feed methods; shovel pontoon (no scarer: $p<0.0001$), frozen block pontoons ($p<0.0001$) and siphon fed pontoons ($p<0.0001$). There was also a significant difference between shovel (no scarer) pontoons and frozen block ($p=0.004$), and frozen block and siphon pontoons ($p=0.025$), but there was no significant difference between shovel (no scarer) and siphon pontoons ($p=0.493$).

There was also a significantly greater abundance of Silver Gulls outside pontoons than inside ($F_{1, 10.4} = 21.3$, $p=0.001$).

Table 3.10: Total Silver Gull abundance at tuna pontoons (2004-2006 years combined). Values that are not significantly different share a superscript.

	Shovel		**Frozen Block**	**Siphon**
	No Scarer	**With Scarer**		
Mean	301*	43	311*	620*
Std Dev	228.4	28.7	380.9	483.8
Range	35-1000	13-120	3-1704	100-1180
N	52	23	106	6

Total Silver Gull abundance at tuna pontoons increased each year for all feed methods, except for frozen block feeding which increased from 2004 to 2005, but decreased again in 2006 (Figure 3.10). However, due to the complexities of the data, it could not be analysed statistically.

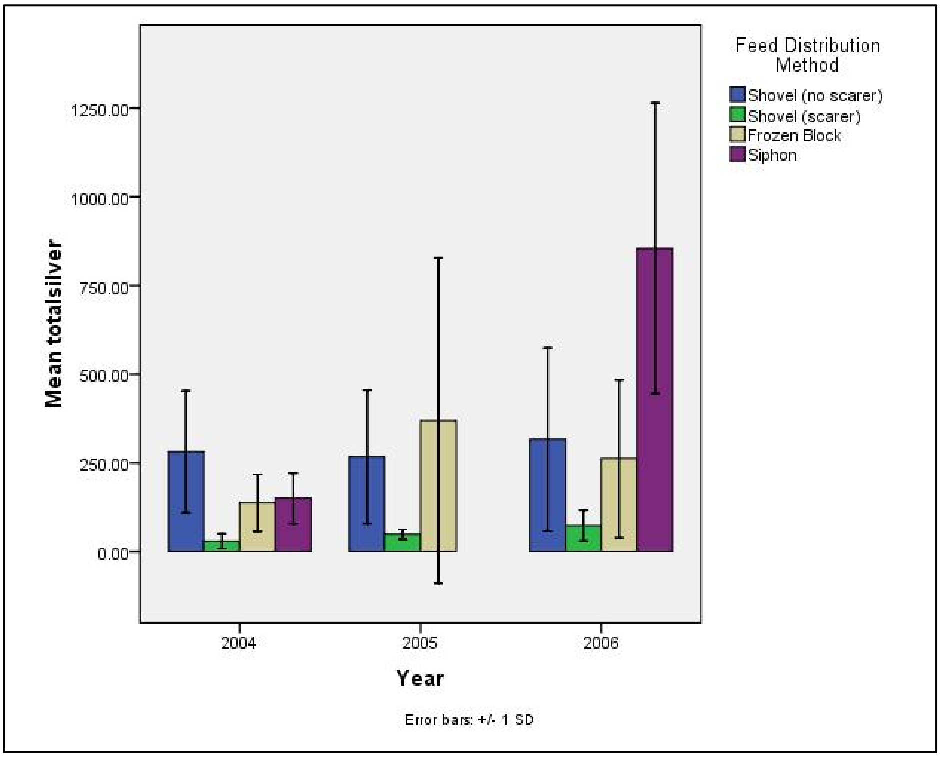

Figure 3.10: Total Silver Gull abundance at tuna pontoons for each feed method for each year of research.

3.3.3.2 Spatial Differences

Silver Gull Abundance Inside and Above the Pontoon (feeding)

There was a significant difference in Silver Gull abundance inside and above the pontoons for the different feed methods (One Way ANOVA (Brown-Forsythe): $F_{3, 80}$ =12.4, p<0.0001). Abundance was highest for shovel feeding without a scarer and lowest for shovel feeding with a scarer, but was intermediate and very similar for frozen block and siphon feeding (Table 3.11). Post hoc comparison using the Tukey HSD method showed these significant differences to be between abundance at shovel feed (no scarer) pontoons and shovel pontoon with a scarer (p<0.0001), shovel (no scarer) and frozen block pontoons (p=0.017), shovel (with scarer) and frozen block (p=0.002), but not between shovel (no scarer) and siphon fed pontoons (p=0.901), shovel (with scarer) and siphon pontoons (p=0.106), and siphon and frozen block pontoons (p=0.959).

Table 3.11: Silver Gull abundance inside and above the pontoon. Values that are not significantly different share a superscript.

	Shovel		Frozen Block	Siphon
	No Scarer	With Scarer		
Mean	85[a]	15[b]	45[bc]	40[abc]
Std Dev	87.2	12.3	60.7	30
Range	2-400	3-50	0-400	20-80
N	52	23	106	6

Silver Gull abundance inside and above the pontoon during shovel feeding without a scarer decreased for each year of research, whilst it remained relatively constant between years shovel feeding with a scarer and frozen block feeding (Figure 3.11).

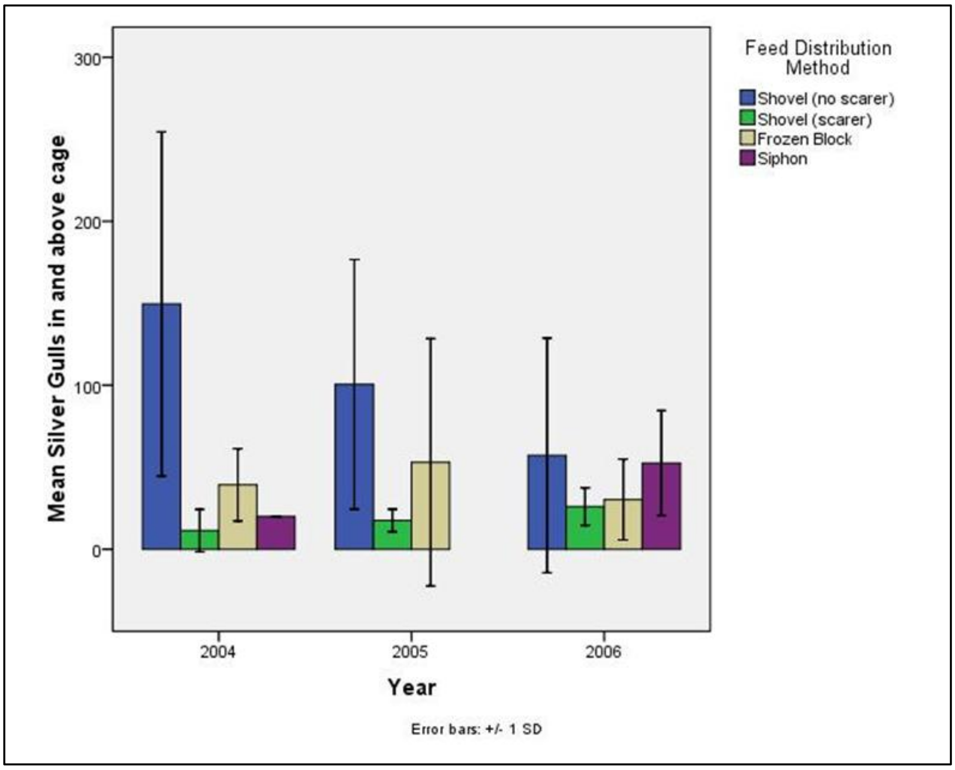

Figure 3.11: A comparison of Silver Gull abundance inside and above the pontoon for each year of research.

Silver Gull Abundance Outside the Pontoon (not feeding)

There was a significant difference in Silver Gull abundance outside of the pontoons using the different feed methods (One Way ANOVA (Brown-Forsythe): $F_{3, 33}$ =27.2, p<0.0001). Silver Gull abundance outside of the pontoon was highest for siphon feeding and lowest for shovel feeding with a scarer. Abundance was relatively similar for frozen block feeding and shovel feeding without a scarer, although the range was much larger for frozen block feeding (Table 3.12). Post hoc comparison using the Tukey HSD method showed the significant differences to be between abundance at shovel fed (no scarer) pontoons and shovel pontoons with a scarer (p<0.0001), shovel (with scarer) and frozen block (p<0.0001) and shovel (with scarer) and siphon pontoons (p<0.0001), but not between shovel (no scarer) and frozen block pontoons (p=0.880), shovel (no scarer) and siphon fed pontoons (p=0.176), and siphon and frozen block pontoons (p=0.081).

Table 3.12: Silver Gull abundance outside the pontoon. Values that are not significantly different share a superscript.

	Shovel		**Frozen Block**	**Siphon**
	No Scarer	**With Scarer**		
Mean	215[ab]	30	265[ac]	580[bc]
Std Dev	191.6	22.5	346.1	455.7
Range	20-900	10-100	0-1700	80-1100
N	52	23	106	6

Silver Gull abundance outside the pontoon increased each year for both shovel feeding methods, but only increased for frozen block feeding from 2004 to 2005 and decreased in 2006 (Figure 3.12).

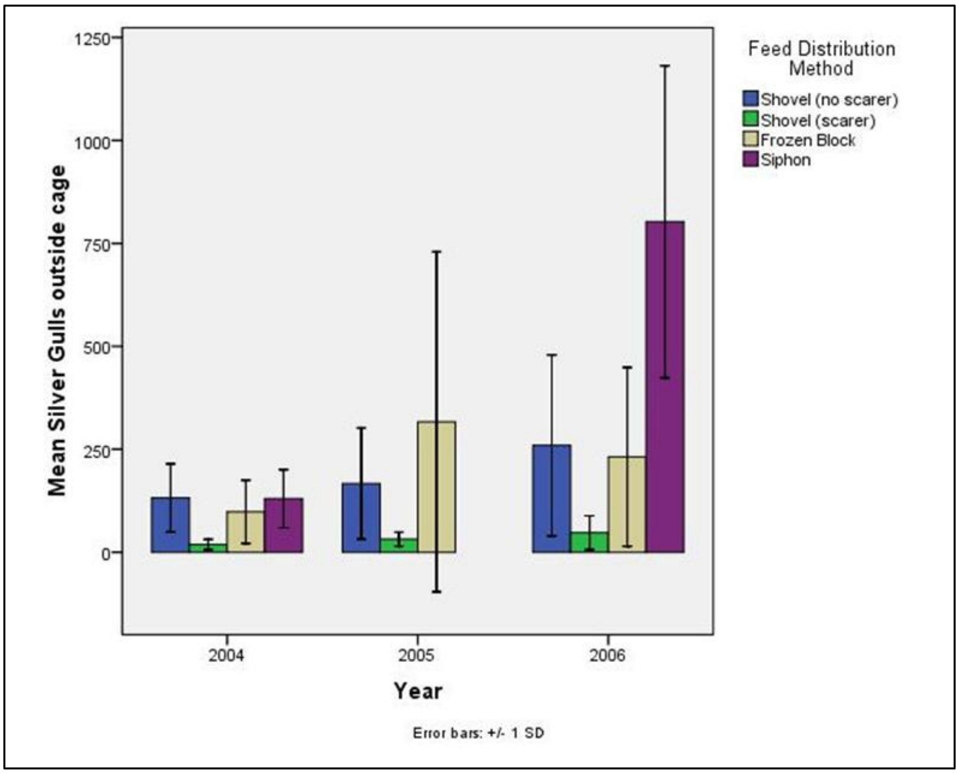

Figure 3.12: A comparison of Silver Gull abundance outside the pontoon for each year of research.

Crested Tern Abundance

The number of Crested Terns at the tuna pontoons was small (<10%) in comparison with Silver Gull abundance. However, there was a significant difference in total Crested Tern abundance at tuna pontoons for the different feed methods (Two Way ANOVA: $F_{3, 254}$ =2.9, p=0.037). Whilst there was a significant interaction between location of the birds and feeding method, there was no significant difference in abundance of Crested Terns between location (inside or outside) (Two Way ANOVA: $F_{1, 9.7}$ =0.05, p=0.830).

Crested Tern Abundance Inside and Above the Pontoon (feeding)

There was a significant difference in Crested Tern abundance inside and above the pontoons for the different feeding methods (One Way ANOVA (Brown-Forsythe): $F_{3, 6}$ =5.5, p=0.033). Abundance was highest for siphon feeding and lowest for shovel feeding with a scarer and very similar for frozen block and shovel feeding (no scarer) (Table 3.13). Post hoc comparison using the Tukey HSD method showed these significant differences to be only between siphon feeding and the other three methods. Thus siphon and shovel (no scarer): $p<0.0001$; siphon and shovel feeding (with scarer): $p<0.0001$; and siphon and frozen block: $p<0.0001$. There was no significant difference between shovel (no scarer) and shovel (with scarer) pontoons ($p=0.328$), shovel (no scarer) and frozen block pontoons ($p=0.997$), and shovel (with scarer) and frozen block pontoons ($p=0.196$).

Table 3.13: Crested Tern abundance inside and above the pontoon. Values that are not significantly different share a superscript.

	Shovel		**Frozen Block**	**Siphon**
	No Scarer	**With Scarer**		
Mean	8^{ab}	2^{ac}	9^{bc}	45
Std Dev	11.1	1.9	15.1	38.1
Range	0-50	0-3	0-100	2-90
N	52	23	106	6

Crested Tern abundance inside and above the pontoon was similar between years for shovel feed with a scarer and frozen block feeding. However, it was much lower in 2005 for shovel feeding without a scarer, than in 2004 or 2006, although abundance remained relatively low over the three years of research (Figure 3.13).

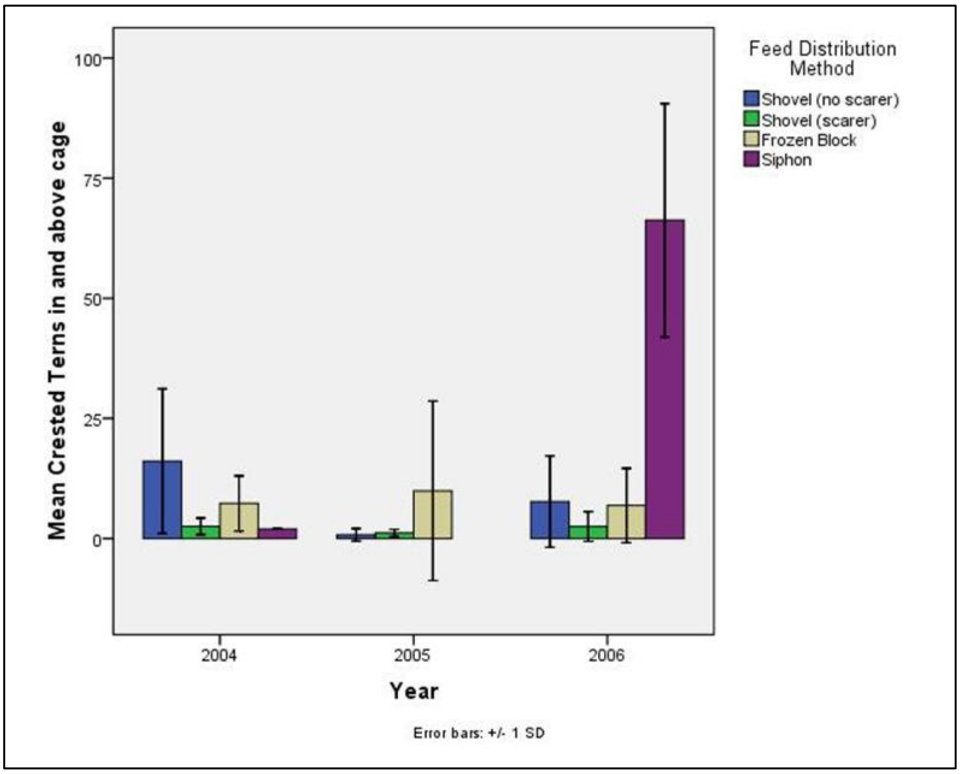

Figure 3.13: A comparison of Crested Tern abundance inside and above the pontoon for each year of research.

Crested Tern Abundance Outside the Pontoon (not feeding)

Crested Tern abundance outside of the pontoons was also relatively low, although there was a significant difference between feeding methods (One Way ANOVA (Brown-Forsythe): $F_{3, 6}$ =5.3, p=0.042). Crested Tern abundance was highest for siphon feeding and lowest for shovel feeding with a scarer, but very similar for frozen block and shovel feeding (no scarer) (Table 3.14). Post hoc comparison using the Tukey HSD method showed the significant differences to be between siphon feeding and the other three methods only. Thus, siphon and shovel (no scarer): p<0.0001; siphon and shovel feeding (with scarer): p<0.0001; and siphon and frozen block: p<0.0001. There was no significant difference between shovel feed (no scarer) and shovel (with a scarer) pontoons (p=0.063), shovel (no scarer) and frozen block pontoons (p=0.194), and shovel (scarer) and frozen block pontoons (p=0.593).

Table 3.14: Crested Tern abundance outside the pontoon. Values that are not significantly different share a superscript.

	Shovel		Frozen Block	Siphon
	No Scarer	With Scarer		
Mean	7[ab]	0.26[ac]	3[bc]	43
Std Dev	11.4	0.9	7.3	41.4
Range	0-45	0-3	0-40	3-90
N	52	23	106	6

Crested Tern abundance outside the pontoon was reasonably similar each year for each feeding method, although it did appear to increase for shovel feeding without a scarer in 2006 (Figure 3.14).

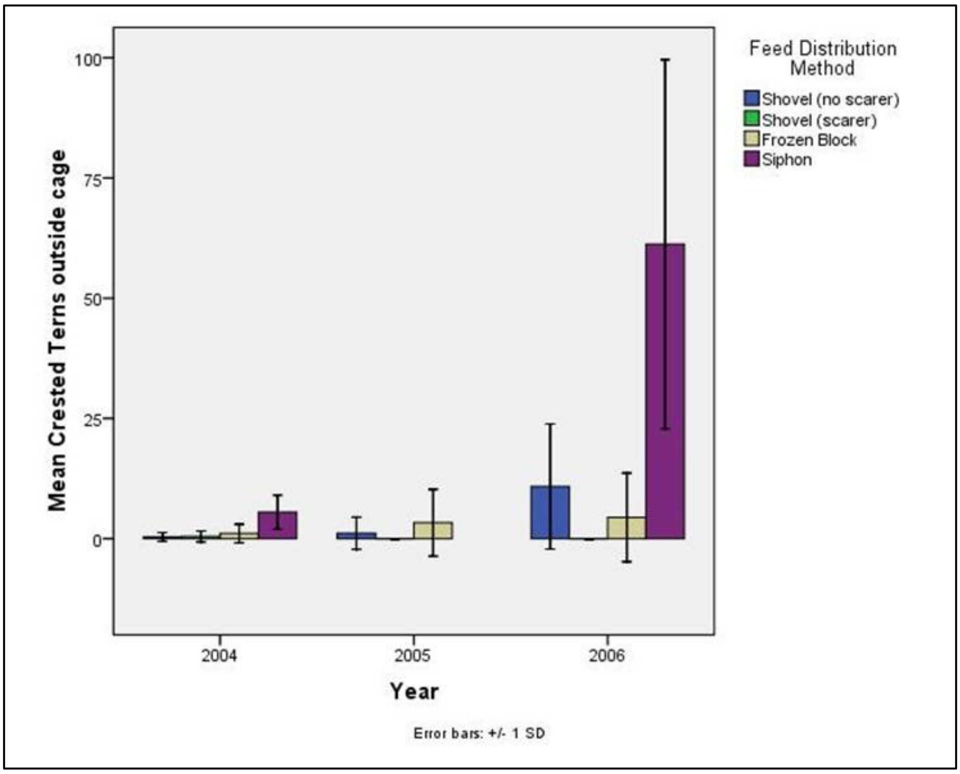

Figure 3.14: A comparison of Crested Tern abundance outside the pontoon for each year of research.

Pacific Gull Abundance Inside and Above the Pontoon (feeding)

Pacific Gull abundance was very low thus the data could not be statistically analysed.

It is evident that Pacific Gull abundance inside and above the pontoons was very similar for each feeding method, for all years of research (Table 3.15, Figure 3.15).

Table 3.15: Pacific Gull abundance inside and above the pontoon.

	Shovel		Frozen Block	Siphon
	No Scarer	With Scarer		
Mean	4	3	1	0
Std Dev	6.8	2.5	2.4	0
Range	0-40	0-10	0-11	0
N	52	23	106	6

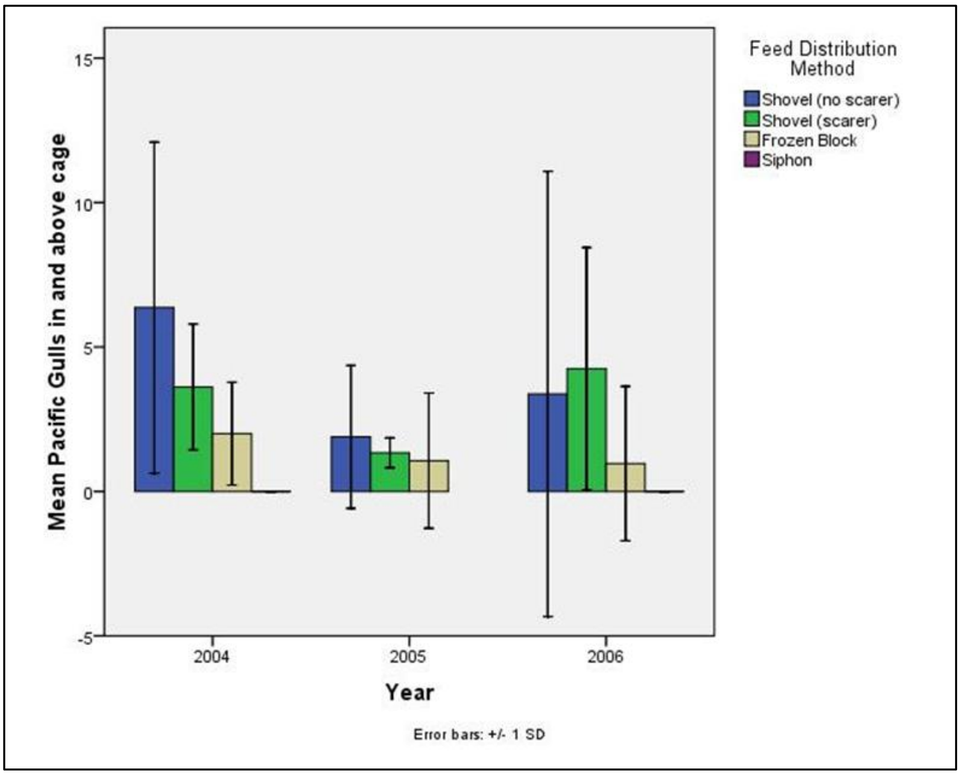

Figure 3.15: A comparison of Pacific Gull abundance inside and above the pontoon for each year of research.

Pacific Gull Abundance Outside the Pontoon (not feeding)

Pacific Gull abundance outside the pontoon was also relatively low, with the highest number outside siphon fed pontoons and lowest outside frozen block pontoons (these data could not be statistically analysed). The range was quite large for all the feeding methods, except for siphon feeding. One company's shovel fed pontoon (no scarer) had 180 individual birds outside, which was the most observed at any one time (Table 3.16). Abundance fluctuated slightly for each feeding method over the three years of research (Figure 3.16). However, it did appear to increase quite substantially for shovel feeding (with scarer) from 2005 to 2006, though the number of feeding sessions was low.

Table 3.16: Pacific Gull abundance outside the pontoon.

	Shovel		Frozen Block	Siphon
	No Scarer	With Scarer		
Mean	15	25	6	35
Std Dev	29.8	43.6	17.9	25.4
Range	0-180	0-150	0-120	0-51
N	52	23	106	6

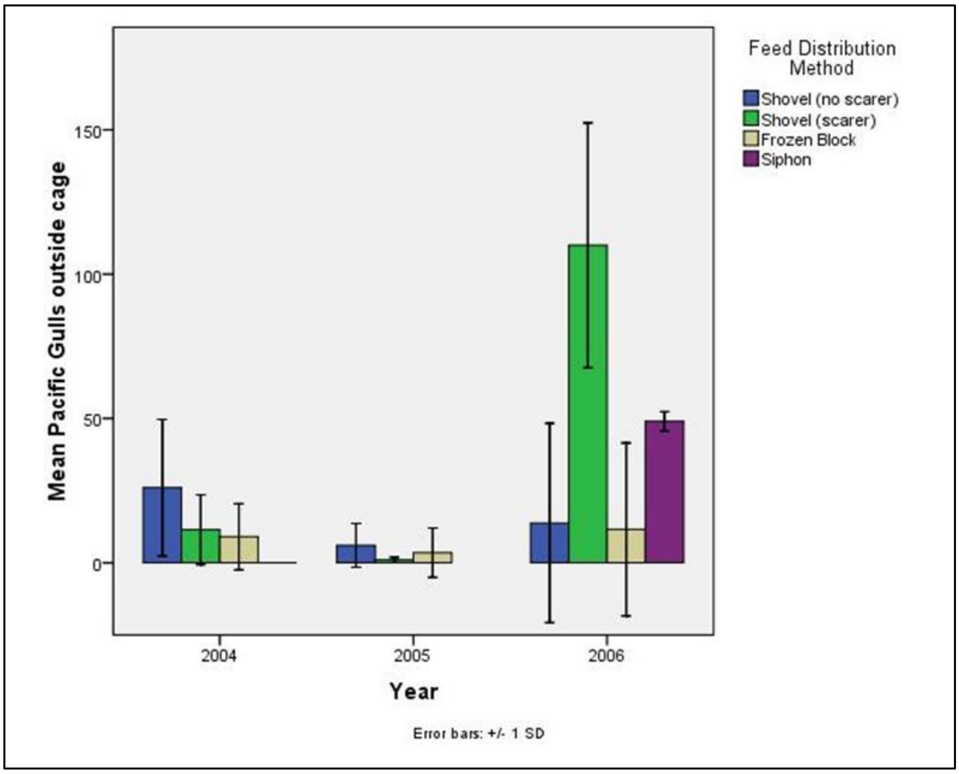

Figure 3.16: A comparison of Pacific Gull abundance outside the pontoon for each year of research.

Short-tailed Shearwater Abundance Inside and Above the Pontoon (feeding)

Short-tailed Shearwater abundance in and above the pontoon was very low for each feeding method, although, 300 were observed feeding at a frozen block cage on one occasion (Table 3.17). Abundance was also quite low for each year of research, although 2005 had the larger range for the feed methods (Figure 3.17). No statistical analysis was possible due to the high number of zero observations.

Table 3.17: Short-tailed Shearwater abundance inside and above the pontoon.

	Shovel		Frozen Block	Siphon
	No Scarer	With Scarer		
Mean	3	0.1	5	0
Std Dev	16.7	0.6	29.6	0
Range	0-120	0-3	0-300	0
N	52	23	106	6

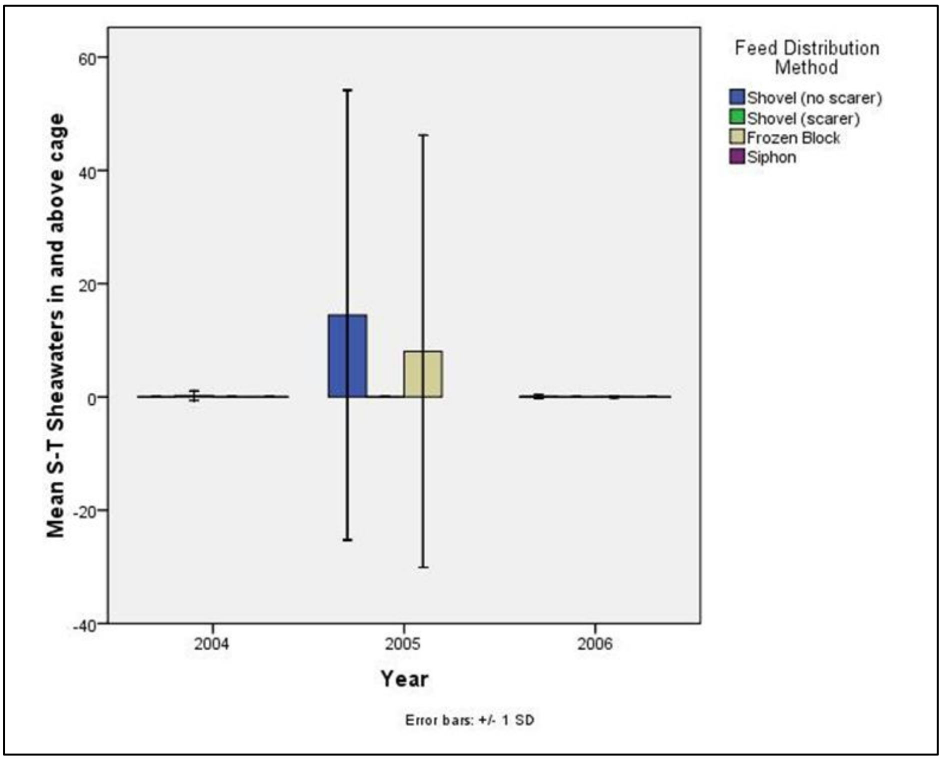

Figure 3.17: A comparison of Short-tailed Shearwater abundance inside and above the pontoon for each year of research.

Short-tailed Shearwater Abundance Outside the Pontoon (not feeding)

Short-tailed Shearwater abundance in general was quite low, although it fluctuated due to the migratory nature of this species. Shearwaters were present during most months of research, but were in their highest abundance in August (data not shown). Mean Short-tailed Shearwater abundance outside of the pontoon was also quite low for each feeding method, except for the frozen block (Table 3.18). The range for this method was also very large, with 2,500 individuals observed on one occasion. Abundance was also highest in 2005 for both shovel feeding (no scarer) and frozen block, but otherwise was quite low in 2004 and 2006 (Figure 3.18).

Table 3.18: Short-tailed Shearwater abundance outside the pontoon.

	Shovel		Frozen Block	Siphon
	No Scarer	With Scarer		
Mean	20	5	135	0.2
Std Dev	102.1	14.4	352.4	0.4
Range	0-550	0-50	0-2500	0-1
N	52	23	106	6

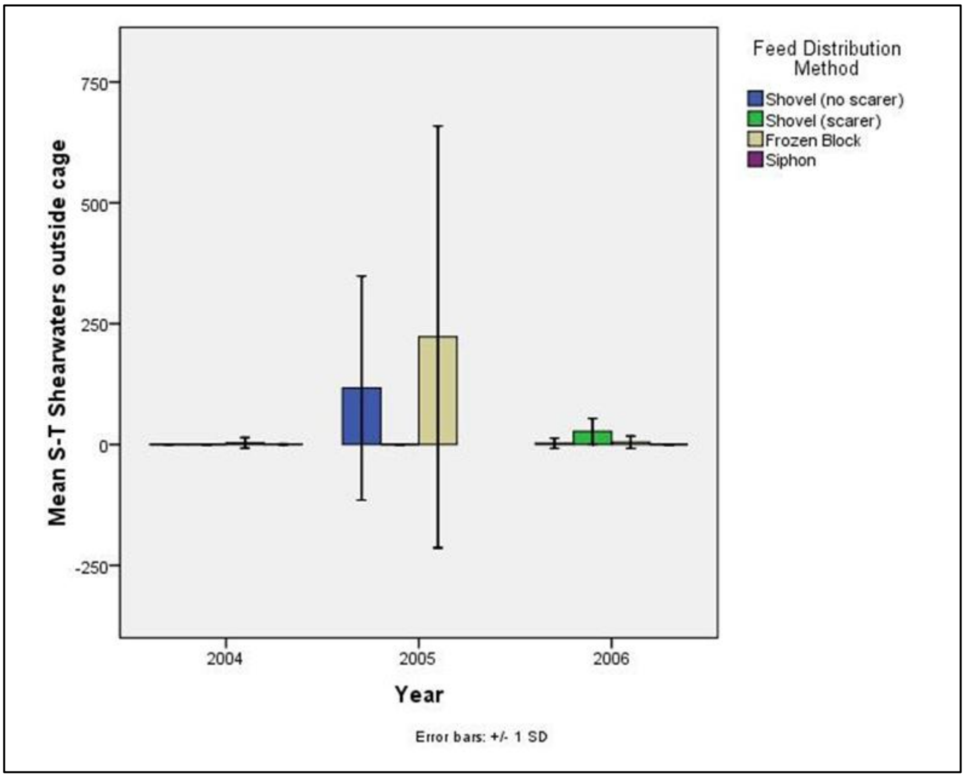

Figure 3.18: A comparison of Short-tailed Shearwater abundance outside the pontoon for each year of research.

3.4 Discussion

Over the course of this PhD project, feed loss to seabirds was studied on eight of the 13 SBT companies farms over three seasons (2004-2006). As found in 2003, the results from this project indicate that shovelling tuna feed results in a significantly greater feed loss to seabirds than the other feeding methods. There was an average loss of 2.38% (48 feeding events) for cages without a scarer for this project, compared to 5.34% in 2003 (one company/21 feeding events) (Harrison, 2003). However, if a scarer was used whilst shovel feeding (observed on two companies - 27 feeding events in total), this significantly reduced the average feed loss to 0.34%, which is a similar result to siphon feeding (0.31%, one company/6 feeding events). Although both of these methods had small sample sizes, they resulted in less feed loss than frozen block feeding, which exhibited higher feed loss during this project (1.08% /106 feeding events) than reported for 2003 (0% /12 feeding events). Some frozen block feed becomes available to seabirds because as blocks thaw, individual baitfish can float out of the feed cage, a situation which is enhanced by freezer burn, cage design/condition and size of baitfish relative to cage mesh. However, as the industry has moved more towards frozen block feeding as their main feed method, (with 75% of feed being distributed using this method (Ellis, pers. comm.)), there is less shovel feed available to seabirds and therefore they may have adapted to obtaining food distributed using this method.

Feed loss to seabirds was quite variable between SBT farming companies, with some losing substantially more than others (shovel 0-6%; frozen block 0.1-2%), and substantial within company variation in feed loss also evident between years. There were also some apparent discrepancies with a few frozen block fed pontoons exhibiting higher feed loss than some shovel pontoons. These differences could have been due to factors such as poor feed cage design, too large a mesh size, small sized baitfish species being distributed, or poor feed cage maintenance, however, none of these factors could be analysed separately. Although a statistical analysis was undertaken to test for differences in feed loss for well designed/maintained cages vs. poorly designed/maintained cages, this was a very broad classification, categorised on the shape and condition of the feed cage above the surface and subsequently no significant difference was found. In hindsight, each feed cage in each pontoon should have been scored for each observation, according to factors such as mesh size on lid, mesh size on sub surface, baitfish size, condition of cage (i.e frame, lid etc) and shape of cage. This would have eliminated problems with the general classification used that did not take into account the fact that cages could be damaged one day and fixed the next, baitfish size relative to mesh size, and even how the cage handles in different weather conditions.

The accuracy of the observational methodology to estimate feed loss from frozen block pontoons is definitely open to debate. Indeed, it is possible to imagine scenarios which suggest that the calculated feed loss percentage could either be under or overestimated. It could be underestimated because the presence of the boat may have deterred birds during the 6-10 minute observation window, and consequently they may have concentrated their scavenging efforts after the boat left the pontoon. In addition, the rate of release of individual floating baitfish during frozen block thawing may not be constant and the thawing times estimated by the skippers could well vary with, for example, with different weather conditions. Either way, these circumstances would challenge the assumption that the initial availability of floating feed was constant for the whole thawing time. In contrast, the calculated loss could be an overestimate because the number of birds attracted to the pontoon by the boat was high in the 6-10 minute observation window and frozen fish on the outside of the block, which would have more freezer burn may float more than those protected on the inside of the block. Ideally observations would have been undertaken throughout the entire thawing time of the blocks, however this was not possible, and this was the best method that could be achieved under the circumstances.

The majority of seabird consumption of fisheries discards research has relied on data from experiments on commercial boats where fish are released singularly and observed for fate over short intervals (10 seconds-3 minutes), due to the difficulty of determining actual discard consumption during commercial fishing (Hill & Wassenberg, 1990; Garthe *et al.,* 1996; Bertellotti & Yorio, 2000; Pierre & Norden, 2006; Cocking *et al.,* 2008). These data are then combined with seabird abundance, calorific value and commercial discard rates to determine total discard consumption (Hill & Wassenberg, 1990; Garthe *et al.,* 1996; Bertellotti & Yorio, 2000; Pierre & Norden, 2006; Cocking *et al.,* 2008). Although there are many widely cited papers which have relied on this methodology, it has been criticised for not providing reliable results in regards to actual commercial fishing practices (Garthe & Huppop, 1998). To overcome this, video taping of discarding has been undertaken, which was also undertaken during this PhD research to calibrate the frozen block (and shovel) feed loss results (Garthe *et al.,* 1996; Walter & Becker, 1997; Martinez-Abrain, 2002). Alternatively, single item discard experiments have been calibrated with multi-item experiments, where more than one discard item (~50) and type is released and observed for a set interval (Garthe & Huppop, 1998), which is similar in principle to the methodology used to determine frozen block feed loss. Therefore, to improve the methodology of this research, more funding would be necessary. This would allow an additional boat to be used so that the observer could remain at the pontoon to observe thawing rates and baitfish consumption by birds at regular intervals, after the feed boat had left (though the presence of any boat is likely to affect seabird behaviour in some way). This method would require long hours at the pontoons to gain a large samples size, as the majority of frozen block feed takes ~2 hours to thaw, which would only allow around three to four feeding events to be observed per day (compared to 6-12 whilst aboard the feed boats). Alternatively, mounting video cameras, both above and below waterline could overcome these shortcomings. However, the number, expense and maintenance of such systems would be considerable. On calm weather days the video data would be relatively easy to analyse, but on rougher days it would be far from easy or pleasant.

The type of baitfish species fed out also affected the amount of feed consumed, with smaller species such as sardines (local and imported Californian and Indonesian), redbait and anchovy taken in the largest proportions and larger species such as herring and Moroccan sardine scavenged in much smaller amounts. This is likely to be due to the handling size of the baitfish, with smaller species being easier to pick up and swallow than the larger species, of which some were too large and heavy for the birds to consume. Fisheries discard experiments have shown that seabirds have a preference for roundfish, like the baitfish fed to the SBT, but they also choose discards according to length or width of the discard component for ease of handling (Garthe *et al.,* 1996; Walter & Becker, 1997). The shorter the handling time the more attractive the fish, and it would seem that the seabirds observed during this project were selecting smaller baitfish as some species/batches were just too large to eat. In terms of reducing feed loss to seabirds, it would appear that the best baitfish to shovel are the larger baitfish, which are obviously harder for the birds to consume. Interestingly, and contrary to expectations, redbait which is quite heavy with a rough surface, was consumed in quite high amounts. Imported frozen block feed loss may have been higher as a result of freezer burn because these fish are in freezers for a long period of time relative to locally frozen baitfish, and freezer burn is at least partly related to storage duration and temperature cycling within the shipment (Carragher, pers. comm.). As mentioned previously, the tuna farming industry requires a large quantity of baitfish (60,000 t p.a.) to feed the tuna and whilst the farm managers try to select baitfish based on characteristics such as fat content, size and price, at this time, their attractiveness to seabirds has not been considered.

The feed losses stated so far have been for seabirds as a whole, however, Silver Gulls were by far the most problematic species, consuming significantly more feed than any other species. Interestingly, they consumed a similar proportion of feed for each feed method, consuming 72% of the scavenged shovelled feed (no scarer), 68% of the shovelled feed with a scarer and 69% of the frozen block feed. Crested Terns, Pacific Gulls and occasionally Short-tailed Shearwaters also scavenged feed but in much smaller proportions. Crested Terns were the second biggest consumer of most feed types except the shovelled feed with a scarer, where Pacific Gulls consumed slightly more than Crested Terns. This latter result is a little surprising as it seems unlikely the most agile bird would be scared off by something they could easily manoeuvre away from, although perhaps the much larger size of Pacific Gulls makes them less threatened by the physical danger of a float than the much smaller Crested Tern. Other factors such as lease location, weather or time of year/season may have influenced these results but there were not enough observations of each of the possible permutations of pontoon characteristics to analyse the data and decipher these trends.

Silver Gulls were the main species consuming baitfish and they were also generally the seabird in the highest abundance at pontoons, both inside and above and outside the pontoon. Abundance inside and above the pontoons was highest at shovel pontoons (no scarer) and lowest at shovel pontoons with a scarer, whilst abundance outside pontoons was much higher at siphon fed pontoons than the other feed types, but was relatively similar for frozen and shovel (no scarer) pontoons. The average total Silver Gull abundance at pontoons over the three years of research was 285, which was lower than the 500 reported for 2003 (Harrison, 2003). However, this is an average of all feed methods over the three years. This extrapolates to 37,050 Silver Gulls at the 130 tuna pontoons (average from 2004-2006: Foote, pers. comm.) on any given day.

Crested Terns consumed the second largest proportion of tuna feed but numbers were generally quite small, although they did increase slightly for each year of research. More were observed outside the pontoon than in, and they were in largest abundance at the siphon fed pontoons. This method was observed once in May 2006, and the time of year may have influenced abundance as Crested Terns breed in the area from November to May (McLeay, pers. comm.), so newly fledged chicks may have been frequenting the farms with their parents. In addition, the lease which was using the siphon feeding method was relatively close to Donington Island, a known roost for this species, which became a breeding site in the summer of 2007/2008 (McLeay, pers. comm.), which may have also influenced abundance.

Unlike Silver Gulls which generally hang around the pontoon or lease, Crested Terns are very mobile and therefore, when the seabird abundance observations were undertaken, it is possible that not all the Crested Terns that visited the pontoon were included in the counts. However, for the relatively small abundance they were successful in gaining food. Crested Terns move their breeding colonies according to food availability (McLeay, pers. comm.). Although there are few historical data on Crested Tern abundance and breeding in the area, Donington Island and Dangerous Reef, which are relatively close to the tuna farms became breeding colonies in 2007/2008 where they had not bred the previous season (2006/2007) (McLeay, pers. comm.). These colonies may be related to the food availability provided by the tuna farming industry which would coincide with a least part of their breeding season (November-May: McLeay pers. comm.)

Pacific Gull abundance was also relatively low, but they were in highest abundance at shovel with scarer pontoons, where they consumed the second highest amount of feed, and were in lowest abundance at frozen block pontoons. Although they were in relatively low numbers on many occasions, there were several occasions where more than 100 individuals were observed outside a pontoon within the company's lease but they had little impact on feed loss. All these birds appeared to be Pacific Gulls, not Kelp Gulls (*Larus dominicanus*), as all observed flying had the black band across the tail feathers, indicative of Pacific Gulls. Unfortunately, very little is known about the population dynamics of Pacific Gulls in the area to relate to these data (Armstrong, pers. comm.).

Short-tailed Shearwater abundance in general was quite low, however, there were occasions where they outnumbered Silver Gulls inside and outside of pontoons. On one occasion there were 300 inside a frozen block fed pontoon and another where 2,500 were counted inside a lease (also frozen fed). The higher abundance at frozen cages may be explained by more frozen cages being observed than any other feed method. However, it could also potentially pose a problem as this species is a diving bird and could compete with the SBT for sub surface feed, although this was not observed, but might occur once the boat leaves. Shearwaters were present during most months of research, but were at their highest abundance in August, probably due to the migratory nature of this species. Abundance was also much higher in 2005 than any other year, however, in general, they had little impact on feed loss and due to the sheer number that migrate to southern Australia to breed, little is known about any small changes in population size.

Apart from being attracted to the pontoons by the obvious food source, these four seabird species also readily use the pontoon structures as perching or roosting sites, rafting in the areas of decreased water movement in the lee of the pontoon and potentially because the pontoons act as FADs (fish aggregating devices) (personal observation). Leatherjackets in particular are known scavengers of excess baitfish under pontoons (Svane & Barnett, 2008) and juveniles of many other species (eg. sandy sprats, sardines, anchovies) shelter and feed on the fouling growth which affects all in-water structures. This is also probably the reason that many other seabird species that don’t scavenge tuna feed were observed foraging in the area such as the Australasian Gannet (*Morus serrator*), Northern Giant Petrel (*Macronectes halli*), Great Skua (*Stercorarius skua*), Little Penguin, several cormorant species and White-faced Storm Petrels (*Pelagodroma marina*).

It is interesting to note that although the averages for feed loss stated above are averages for three years of research combined, with not all companies being used every year, the data do indicate that the amount of feed being consumed by birds decreased slightly each year, as did seabird abundance in general. This may be due to an increase in awareness of scavenging seabirds as a problem or as a consequence of tuna farming profit margins decreasing for several years with the industry responding by feeding more with frozen block and less by shovelling.

Although the estimation method used to quantify feed loss was reasonably accurate, the variability may need to be addressed for future use. However, it does utilise observations from commercial operations and not from timed experiments, as occurs in fisheries discard research and therefore is probably a better indicator of actual results than if separate experiments were undertaken. The calibration exercise (i.e. simultaneous video taping and ‘real time’ observations of the same feeding events) undertaken during this project does show that the observational approach is reasonably accurate (within 10% (proportional) in most cases). However, on average it does slightly underestimate shovel feed loss (-0.21%) and slightly overestimates frozen block feed loss (+0.03%), but variability increases as feed loss increases which is where the accuracy issue lies. If this methodology was utilised in the future, a correction factor could be applied to improve the accuracy if the variability observed was not deemed ideal.

Assuming that the companies that cooperated in this study were representative of what occurs in the industry as a whole, it is possible to estimate the amount of baitfish feed lost to seabirds each farming season. The average absolute feed loss rates for shovelled baitfish (no scarer) was 2.38%, shovelled baitfish (with scarer) was 0.34% and frozen block loss rate was 1.08%. The other assumptions were that companies that did not participate in the research did not use scarers, that 25% of the feed was shovelled and 75% frozen block (Ellis, pers. comm.) and that the total annual mass of baitfish used across the whole industry was 60,000 t. Under these circumstances it is estimated that ~790 t (1.3% (absolute %)) of baitfish is taken by seabirds each year, with Silver Gulls consuming ~570 t (70% (proportional %)), Crested Terns ~134 t (17%), Pacific Gulls ~71 t (9%) and Short-tailed Shearwaters ~32 t (4%). However, the abundance data suggests 37,050 gulls were at the tuna farms each day, and they would consume ~534 t ((37,050 *60g per gull per day)*240 days (Appendix 2). Although a 1.3% loss of tuna feed to seabirds is quite high, it is lower than the estimated 3% of feed that is lost below the SBT pontoons (Fernandes *et al.*, 2007[b]) of which the majority is consumed by benthic scavengers (notably Degens Leatherjacket *Thamnaconus degeni* and sea lice) (Svane & Barnett, 2008). However, it is believed that losses to birds could be considerably reduced, saving the industry unnecessary wasted money through proper mitigation methods.

In conclusion, approximately 1.3% (790t) of SBT feed is consumed by seabirds, of which ~70% is consumed by Silver Gulls. However, the amount scavenged can be decreased by using a scarer whilst shovel feeding or feeding frozen block, but ensuring that the feed cage is well maintained with a small mesh size and a large baitfish species. The scaring devices utilised need to be tested further to determine their efficacy in reducing scavenging rates of seabirds.