CHAPTER ONE

GENERAL INTRODUCTION

1.1 General Overview

Birds have interacted with humans for thousands of years, but as human populations have grown exponentially we have encroached further into bird habitats and these interactions have become more intense. Thus over the last century, the abundances and distributions of a large number of bird species in many habitats around the world have been increasingly impacted by human activities. While some bird species populations have been negatively impacted with declining populations, the opposite is also true, with some species flourishing. For example, the increased availability and abundance of anthropogenically created resources has been associated with an increase in many bird populations that have adapted to utilise these resources (Bosch *et al*., 1994; Belant, 1997). Resources and habitats include landfill, rooftops, buildings, airfields, golf courses, agricultural fields (Blackwell *et al.*, 2000), fisheries discards (Garthe *et al*., 1996; Oro *et al.*, 1996) and aquaculture farms (Price & Nickum, 1995; Glahn *et al*., 1999). The successful species can be native or introduced and some of them become problematic because their populations grow too large and begin affecting human activities. There are many examples around the world including many species of gulls (eg. Herring (*Larus argentatus*) and Ring-billed (*Larus delawarensis*) Gulls in the USA (Belant, 1997) and Silver Gulls (*Larus novaehollandiae*) in Australia (Smith, 1995)); waterbirds (Canada Geese (*Branta canadensis*) (Christens *et al.*, 1995) and cormorants (*Phalacrocorax* sp.) (Glahn *et al.*, 1999) in the USA and Australian White Ibis (*Threskiornis molucca*) in Australia (Martin & Dawes, 2005)); as well as other terrestrial species in Australia including Common Myna (*Acridotheres tristis*), European Starlings (*Sturnus vulgaris*), feral

Pigeons (*Columba livia*) and cockatoo species such as Little Corellas (*Cacatua sanguinea*) and Galahs (*Cacatua roseicapilla*) (DAFF, 1997).

A variety of gull species have been among the most opportunistic in taking advantage of human food sources and this has contributed to the rapid increase in their populations worldwide over the last century, with the concurrent increase in negative human/gull interactions (Belant, 1997). Gulls belong to the Order Charadriiformes, which include both shorebird and seabird species. Whilst gulls fit under the definition of both, the majority of the literature relevant to this research class gulls as seabirds (eg. Furness, 1996; Garthe *et al*., 1996; Walter & Becker, 1997; Oro, 1999; Huppop & Wurm, 2000; Bertellotti *et al*., 2001; Martinez-Abrain *et al*., 2002; Furness, 2003; Svane, 2005), and so that is the classification that will be used in this thesis.

While the availability of 'natural' food for many seabirds is spatially and temporally unpredictable (Bertelloti *et al*., 2001), food sources of human origin such as those from waste tips are usually relatively abundant and predictable in space and time (Furness, 1996; Oro, 1999; Bertellotti *et al*., 2001). In addition, human exploitation of marine resources has provided an increasing opportunity for some seabirds to take advantage of foods that would otherwise be unavailable to them (Furness *et al*., 1988). Fish and crustaceans are cultivated in coastal ponds and inshore seacages and thousands of tonnes of fisheries by-catch and offal are discarded each year from the fishing industry throughout the oceans (Price & Nickum, 1995; Garthe *et al.*, 1996). As seabirds naturally forage for food in intertidal, inshore and offshore areas of the coast, aquaculture practices and fisheries discards activities are thus an extension of their natural foraging zone (Serventy *et al.*, 1971; Glahn *et al.*, 1999; Martinez-Abrain *et al*., 2002).

1.2 Bird-Aquaculture Interactions

Aquaculture is becoming increasingly important as a food source for an expanding human population, particularly with declining wild stocks available to fishing (FAO Fisheries Report, 2007). However, the industry must ensure that its production is environmentally sustainable and does not outweigh its environmental carrying capacity (FAO Fisheries Report, 2007).

Inevitably, aquaculture operations interact with the surrounding environment. Aquaculture can create negative impacts on that surrounding environment (e.g. Shaughnessy, 1993; DEPWHA, 2001; Edgar *et al.*, 2005; Vita & Martin, 2007), whilst the environment can also have negative implications for aquaculture operations (e.g. Carss, 1993; Pemberton & Shaughnessy, 1993; Nash *et al.*, 2000). The impact or relationship that is relevant to this thesis research is the interaction between piscivorous (or semi-piscivorous) birds and aquaculture. Piscivorous birds are naturally attracted to aquaculture facilities by the concentration of a predictable, potential food source (EIFAC, 1988; Price & Nickum, 1995; Avery *et al.*, 1999; Glahn *et al.*, 1999). Ponds and seacages can also provide an attractive habitat for wading, congregation and roosting (Howell & Munford, 1991; Bochenski, 1995). In addition, the structures (suspended nets and frames) provide a substrate for aquatic organisms to colonize. This also attracts wild fish, which seek the food and shelter provided by the attached plants, invertebrates and uneaten food pellets and waste material, which in turn attracts piscivorous birds (Howell & Munford, 1991).

In both freshwater and marine aquaculture, birds can cause substantial economic losses through both direct and indirect mechanisms. Losses are incurred through:

1. Stock losses through direct predation, mortality from predator wounds or escapees from bird damaged nets.
2. Reduced marketability of fish through damage to skin/scales/flesh.
3. Interference with artificial feeding that reduces efficiency.
4. Increased risk of disease or continuation of disease outbreaks.

In addition, birds may be unintentionally killed or harmed by operations or mitigation measures such as shooting (non-target species) or their entanglement in nets erected to prevent them from landing or consuming farmed products (Ronconi *et al.*, 2004). An example is the death of several, protected White Breasted Sea Eagles (*Haliaeetus leucogaster* – only 200 in Tasmania) due to entanglement in Tasmanian Atlantic Salmon (*Salmo salar*) seacage anti-predator nets or entrapment in fish disposal pits (DEWHA, 2001). These types of occurrences have potential negative marketing implications because consumers are less likely to buy products that are not considered environmentally friendly (eg. the high demand for 'dolphin-friendly' tuna).

Bird predation of aquaculture stock is the main reported problem causing economic concerns (Galbraith, 1992; Carss, 1993; Price & Nickum, 1995; Furness, 1996; Glahn *et al.*, 1999). Most problems occur on large inland farms with densely stocked fish that are highly visible from the air and hence attractive to birds (Price & Nickum, 1995). These farms usually culture trout (*Oncorhynchus* sp., *Salmo* sp., and

Salvelinus sp.), salmon (*Oncorhynchus* sp., *Salmo* sp.), baitfish (*Notemigonus chrysoleucus*, *Pimephales promelas*, *Carassius auratus*) catfish (*Ictalurus punctatus*) and crayfish (*Procambarus clarkii*) in a variety of sizes and thus appropriately sized prey are potentially available to birds all year (Price & Nickum, 1995; Glahn *et al*., 1999). Waterbirds cause the main conflicts on land based aquaculture farms. In order of importance, the problematic waterbirds in Europe are pelicans (*Pelecanus* sp.), cormorants (*Phalacrocorax* sp.), herons (*Ardea* sp.), egrets (*Egretta* sp.) gulls (*Larus* sp.) and grebes (*Podiceps* sp.) (EIFAC, 1988). Similarly in the USA and Canada, cormorants, egrets, herons, pelicans and gulls are the main problems (Price & Nickum, 1995). In both Europe and the USA ducks (*Anas* sp., *Somateria* sp., *Melanitta* sp., *Aythya* sp.), swans (*Cygnus* sp.), coots (*Fulica* sp.), night herons (*Nycticorax* sp.), grackles (*Quiscalus* sp.), terns (*Sterna* sp.) and kingfishers (*Megaceryle* sp. *Alcedo* sp.) can also be an issue (though to a lesser extent) (EIFAC, 1988; Avery *et al.*, 1999; Glahn *et al.*, 1999). Birds can cause stock losses of up to US$10,000 (20% loss of production) per farm per year (Glahn *et al*., 1999), with an annual loss of up to US$25 million or a 20% loss in production in the south-eastern USA catfish industry alone (Glahn *et al.*, 2002). In the Louisiana crawfish industry a conservative estimate of stock losses is estimated at US$6.6 million (25% of non-management losses) (Price & Nickum, 1995). Whilst the USDA (2003) estimates that US$17 million is lost to bird predation in the American finfish aquaculture industry per year. In Europe (carp (*Cyprinus* sp.) and salmon), damage and losses from birds is estimated at 10-60% of production costs (Price & Nickum, 1995). In Romania, which was the largest European freshwater aquaculture producer at the time (mainly carp species), annual losses were estimated at 20% of production or about US$6.4 million per year (EIFAC, 1988).

Whilst densely stocked fish are generally more susceptible to disease, wounds incurred by birds make them even more so. Indirect losses from birds are incurred through wounds making fish non-marketable, the continual presence of predators stressing fish or competing with them for food (decreasing food intake and reducing growth), wounds leading to bacterial and fungal infections that weaken or kill and stressed fish that are also more susceptible to disease (EIFAC, 1988). Whilst it is hard to quantify losses due to stress created by birds alone, wounds are easily recognised and therefore mortality due to wound inflicted by birds is easily quantified. The value of these indirect losses may equal the value of those incurred directly (EIFAC, 1988).

Although most of the reported aquaculture/bird interactions occur on land based farms, these interactions also occur at water-based aquaculture farms (Price & Nickum, 1995). The species involved include gulls, herons, ducks, Ospreys (*Pandion haliaetus*) and eagles (*Haliaeetus* sp.) (Price & Nickum, 1995; DEWHA, 2001; Huon Aquaculture, pers. comm.). In many cases, predation rates are low, but can be as high as 7% for freshwater trout farms in Scotland (Carss, 1993) and 64% of the annual yield of eel (*Anguilla anguilla*), mullet (*Mugil* sp.), gilthead seabream (*Sparus aurata*) and sea bass (*Dicentrarchus labrax*) at a fish farm in France (Lekuona, 2002). In the UK, mussels (*Mytilus edulis*) are taken by Eider Ducks (*Somateria mollissima*) and scoters (*Melanitta* sp.) (Galbraith, 1992) and salmon are taken from seacages by gulls, herons and Ospreys (Carss, 1993; Price & Nickum, 1995; Furness, 1996). However, bird predation is generally a minor issue compared to interactions with marine mammals (Furness, 1996).

Feed loss to scavenging birds can also be quite costly particularly as some birds learn to directly feed on the pellets used as artificial fish feed, especially with the increasing use of floating pellets (Harpaz & Clarke, 2006). In Europe, swans, coots, and ducks, especially Mallards (*Anas platyrhynchos*), compete directly for food pellets intended for farmed fish (Price & Nickum, 1995), and in Poland, 2-7.4% of the food intended for carp was consumed by waterbirds (EIFAC, 1988). In Scotland, gulls tear open bags of pellets and consume an un-quantified proportion of improperly stored feed at salmon farms (Furness, 1996). Similarly, Silver Gulls scavenge the pellet feed of Atlantic Salmon in Tasmania (Huon Aquaculture, pers. comm.). However, in comparison, feed loss below the cages can be more significant, especially for pellet fed operations, with average losses around 20% (Islam, 2005), although it can range from 1-30% depending on the moisture content of the pellet (feed loss increases with moisture content) (Warrer-Hansen, 1982). However, feed loss was reported to be much lower on the Southern Bluefin Tuna (*Thunnus maccoyii*) industry farms in Port Lincoln with an estimated 3% of baitfish feed lost beneath the pontoons (Fernandes *et al.*, 2007[b]). All levels of feed loss reported are economically significant given feed costs can be up to 50% of an aquaculturist’s production budget (Price & Nickum, 1995).

Apart from birds consuming fish and fish food, losses can also be incurred through transmission of fish disease and parasites from pond to pond and farm to farm. In Europe, birds have been implicated in the transmission of three fish viruses: Spring Viraemia of Carp (SVC), Viral Haemorrhagic Septicaemia (VHS) and Infectious Pancreatic Necrosis (IPN) (EIFAC, 1988). Similarly, American White Pelicans (*Pelecanus erythorhynchos*) have been reported to transmit a parasite that infests commercially grown catfish in the mid-South USA (Overstreet *et al.*, 2002; King, 2005).

Transmission can occur mechanically via regurgitated fish, by faecal transmission (if the pathogen can be carried in the avian gut) or on their feet (Price & Nickum, 1995). Birds are also intermediate or definitive hosts to numerous cestodes, nematodes, trematodes and other parasites (Price & Nickum, 1995). In many cases, birds transmit parasites or their eggs to crustaceans or molluscs that are the infective agent for the fish (Price & Nickum, 1995). Gulls can be vectors for many problematic pathogens and parasites. For example, gulls have been shown to carry and transmit the causative bacterial agent of Enteric Redmouth Disease (ERM), salmonid whirling disease and various penaeid shrimp viruses in their faeces and spread the pathogens on farms and hatcheries (EIFAC, 1988; Vanpatten *et al.*, 2004). In Nova Scotia, one land based salmon farm was shut down due to an infestation of the gull worm parasite (*Diphyllobothrium dendriticum*) (which has human and fish health implications) that reduced production by 50% and installing a water filtration system was too costly to justify the expense (EIFAC, 1988).

Aquaculture has also had a direct positive impact on many populations of waterbirds. In some cases fishponds are a substitute for their declining natural habitats and provide nest sites and foraging habitats (Bochenski, 1996). For example, fishponds are the main breeding habitat of waterbirds in Poland (Bochenski, 1996). While aquaculture facilities can affect the distribution of many birds by attracting breeding and non-breeding birds, the resources provided by these facilities can also influence their population size. In Louisiana, USA, the increasing populations of colonial waterbirds that utilise crayfish farms is strongly positively correlated with the commercial crayfish pond acreage (Fleury & Sherry, 1995). These waterbird populations increase due to food availability during their breeding season (Werner *et al.,* 2005). This food source not only affects breeding birds but also enhances the over winter survival of several species (Belant *et al.,* 2000). For example, the abundance of Double-crested Cormorants (*Phalacrocorax auritus*) wintering in the delta region of the Mississippi has increased 250% in the last decade and this has been attributed to their use of the cultivated catfish, impoundments, costing the industry US$2 million a year in predated stock (Werner & Dorr, 2006).

1.3 Interactions between Seabirds and Discards from Fisheries

Unlike aquaculture, where birds consuming fish or fish feed are perceived as a significant problem, fisheries discards, which are freely available to many coastal seabirds, are not often seen in a negative light by the public. Extensive research on the exploitation of commercial fisheries by scavenging seabirds has shown that in many regions such as the North Sea and the Mediterranean, fisheries discards are usually the main foraging resource for some seabird populations (Garthe *et al*., 1996; Oro *et al.*, 1996; Gonzalez-Solis, 1997; Walter & Becker, 1997; Huppop & Wurm, 2000; Bertellotti & Yorio, 2000; Martinez-Abrain *et al*., 2002; Votier *et al.,* 2004). The discards from commercial fisheries usually comprise several species of roundfish, flatfish, deep bodied fish, elasmobranchs, cephalopods, benthic invertebrates and fish offal, although the proportions of each depend on fisheries type and region (Hill & Wassenberg, 1990; Blaber *et al*., 1995; Garthe *et al*., 1996; Walter & Becker, 1997; Bertellotti & Yorio, 2000; Huppop & Wurm, 2000; Martinez-

Abrain *et al*., 2002; Svane, 2005). The majority of the fisheries discards float and can be available to birds and other marine animals for up to six hours (Blaber *et al*., 1995). The seabirds able to exploit the activities of commercial fishing boats are opportunistic scavengers, which include many gull species (Garthe *et al*., 1996; Walter & Becker, 1997; Huppop & Wurm, 2000; Martinez-Abrain *et al*., 2002), but also include skuas (*Stercorarius* sp.), gannets (*Morus* sp.), kittiwakes (*Rissa* sp.), terns, cormorants, albatrosses (*Diomedea* sp., *Phoebastria* sp., *Phoebetria* sp., *Thallassarche* sp.), petrels (*Macronectes* sp.) and fulmars (*Fulmarus* sp.) (Furness *et al*., 1988; Blaber *et al*., 1995; Garthe *et al*., 1996; Oro, 1996; Huppop & Wurm, 2000).

The proportion of discards in the diet of seabirds can range from 20% for Crested Terns (*Sterna bergii*) on the Great Barrier Reef (Blaber *et al*., 1995) to 73% for Audouin's Gull (*Larus audouini*) in the western Mediterranean (Oro, 1997) and 100% for some gulls in the North Sea (Huppop & Wurm, 2000). In the British Isles, the numbers of all scavenging seabirds have increased over the last century. This has been attributed to the availability of fisheries discards, and those species that are the most competitive at fishing boats seem to be increasing most rapidly (Furness *et al*., 1988). The quantity of discards available in the British Isles area could support 2.5 million, 1kg seabirds, whereas 3 million are actually present (Furness *et al*., 1988). About 150,000 breeding pairs of seabirds are supported by discard availability in the Wadden Sea (Walter & Becker, 1997). In the North Sea, there is sufficient fisheries waste to satisfy the energy demands of all scavenging species and it could potentially support 5.9 million birds (Walter & Becker, 1997). Observations have shown that 39% of the total discards in the area were consumed by seabirds, which more than equates to the 250,000 tonnes of live fish estimated to be required by these birds (Garthe *et al*., 1996). Similarly, in the western Mediterranean Sea up to 72% of discards are taken by seabirds (Martinez-Abrain *et al*., 2002).

The dependence of seabirds on discards is amply demonstrated by the large population of Great Black-backed Gulls (*Larus marinus*) on Helgoland Island in the German Bight of the North Sea. They depend on the fisheries waste in the area to support them, as there is no alternative food source to support such a large number of gulls (Huppop & Wurm, 2000). Their seasonal pattern reflects this dependence, as when fisheries stop over Christmas, the gulls move elsewhere, and when the fishery activity resumes, they return to the island (Huppop & Wurm, 2000). Another dramatic example of dependence on discards is Audouin's Gull (*Larus audouini*) in the Ebro Delta of the Mediterranean. This gull was so threatened 22 years ago that only a few pairs remained, but by 1994 there were 10,000 pairs (70% of the world's population) and this was attributed to the availability of trawler discards (Oro *et al.*, 1996). Observations suggest 73% of this population's diet is discards and it is so dependent on this food source that it is thought it may once again become threatened if a trawling moratorium continues for many years (Oro *et al.*, 1996).

While fisheries discards can support a large number of birds, there is a high incidental mortality rate of those birds at vessels with different fishing gear such as gill nets, drift nets, trawl nets and longlines all capable of entangling and drowning the birds (Gonzalez-Zevallos *et al.*, 2007). Unfortunately many seabird species are still classified as endangered, and hence unless the high mortality rate is reduced, these activities could result in the extinction of several albatross and petrel species within our lifetime (Environment Australia, 1998; Prado, 2000; Gilman, 2001).

1.4 Human Refuse

Waste sites constitute predictable and abundant food sources that are widely used by many gull populations around the world (Yorio & Caille, 2004). In addition, the food is usually renewed daily and increases as the human population grows. These food sources have been implicated in the growth of gull populations in both the northern and southern hemisphere (Smith, 1995; Yorio & Caille, 2004). For example, on Big Island, off the coast of Wollongong, NSW, Australia, breeding numbers of Silver Gulls have grown from a few pairs prior to 1940 to 51,500 pairs in 1978, levelling off to 50,000 pairs in 1991 (Smith, 1995). When the diets of adult and young in the nesting colony were determined from regurgitations in the late 1980s and early 90s, 82% consisted of human refuse and 18% was of natural food (Smith *et al.*, 1991). They also found that 74% of the population fed at the nearby waste depot and 82% of all feeding forays were to this depot.

This reliance and population growth has been observed for other gulls associated with refuse tips (Bosch *et al.*, 1994). The diet of breeding Yellow-legged Gulls (*Larus michahellis*) was 53-74% human refuse in France (Duhem *et al.*, 2003) and 60% in Spain (Bosch *et al.*, 1994). Interestingly, population growth was much lower for the colony in Spain as the availability of the food source was the limiting factor (Bosch *et al.*, 1994).

Nesting Ring-billed Gulls (*Larus delawarensis*) along the Canadian portion of the Great Lakes have increased from 56,000 pairs in 1976 to 283,000 pairs in 1990 with

99% of the food mass being anthropogenic (Belant *et al.*, 1998). This population is likely to continue to increase as long as human refuse is available (Belant *et al.*, 1998). Herring Gulls (*Larus argentatus*) in France also rely on urban waste sites for food with 71% of the Treberon colony observed at the dump and 61-85% of the diet human refuse (Pons, 1992). The introduction of an incinerator reduced the amount of waste by 80%, yet the amount of refuse in the gulls' diet was only reduced to 50%, but the abundance of breeding pairs fell by 11.5% and there was a decrease in clutch size, egg size, hatching success and fledging success. In addition, most chicks died within 10 days of hatching with most of the deaths being due to cannibalism, which was non-existent before the introduction of the incinerator (Pons, 1992).

While human refuse increases many gull populations, most of the food has low nutritional value, and population growth seems to be due to sheer quantity of edible rubbish. However, this 'junk food lifestyle' has been reported to have the same effect on Silver Gulls as on humans, creating overweight birds with high cholesterol and high blood glucose levels (Auman *et al.*, 2008).

In addition to urban waste, many coastal refuse depots also take fish processing factory waste, which unlike most refuse may greatly benefit gull survival and breeding success due to its higher nutritional value (Yorio & Caille, 2004). It was calculated that the waste from a seafood processing plant in Argentina could support a population of between 101,000 and 209,000 Kelp Gulls (*Larus dominicanus*) while the actual breeding population was 90,000 adults (Yorio & Caille, 2004). These gulls use this waste throughout the year and the population has increased at a rate of between 2% and 63% per annum. Observations showed that 54-69% of the colony used the tip and more gulls utilised the fish waste rather than the urban waste (Bertellotti *et al.*, 2001).

Direct feeding of birds by humans can also create population increases and dependency. Many species of waterfowl, pigeons, gulls and even backyard birds habituate to such a food source and it can lead to large populations of pest birds congregating and causing a nuisance (Ehrlich *et al.*, 1988; Connecticut Department of Environmental Protection, 2007). While people enjoy feeding birds and may regard it as helping the birds, it can lead to many negative effects such as expansion of home ranges, loss of fear of humans, malnutrition, weak birds surviving over winter, and can even result in migratory birds ceasing to migrate (Ehrlich *et al.*, 1988). In Australia, feeding seagulls is a common occurrence that has created problems in coastal towns such as Victor Harbour, South Australia, where an inflated seagull population is a nuisance (The Advertiser, 2004).

1.5 Problems Caused by Artificially High Bird Populations

The availability of large quantities of predictable food increases seabird populations by improving breeding success, decreasing mortality and increasing recruitment. An abundance of good quality food can increase clutch size, egg weight and volume, hatching success, chick survival and fledging success (Annett & Pierotti, 1989; 1999). This inevitably increases the populations of opportunistic and scavenging birds (Smith & Carlile, 1993; Smith, 1995; Belant, 1997). These inflated avian populations in urban areas sometimes conflict with human activities and engender a range of problems including the following:

Bird-strikes

Airports are often surrounded by landfills, wetlands and other habitats that attract a variety of bird species (USDA, 2003). Birds can be a threat when they collide with aircraft in ‘bird strikes’ that can severely damage engines, cause exterior damage and in some cases lead to crashes (ATSB, 2002; 2007; USAD, 2003; Dolbeer, 2006). The economic losses are estimated worldwide at $US3 billion annually with 195 aircrew and passenger deaths due to bird strikes since 1988 (ATSB, 2002; 2007). Thus, bird strikes are one of the greatest potential hazards arising from human bird interactions (Temby, 2004). Bird strikes have been increasing steadily at major aerodromes around Australia over the years with 318 strikes in 2000 to 593 in 2004 (ATSB, 2007). At the Kingsford-Smith Airport in Sydney bird strikes and daily deterrence of birds cost around $360,000 per annum (Smith, 1995).

Transmission of disease and risks to human health

There is currently considerable concern about avian influenza, a viral infection that occurs naturally in birds and can be transmitted to humans (CDC, 2006). The strain Avian Influenza A (H5N1) has crossed the species barrier to infect humans causing severe disease symptoms and death in humans (CDC, 2006). The continued growth and geographic expansion of birds species such as waterfowl into rural and urbanised settings provides more opportunity for them to interact with humans and livestock, and in the nature of these interactions, may represent and increased risk of pathogen transmission.

Australian White Ibis (*Threskiornis molucca*) is an overabundant species that hosts zoonotic and livestock pathogens such as *Salmonella* spp., Newcastle disease virus, avian influenza virus and flaviviruses (Epstein *et al.*, 2006). Pigeons are known to transmit ornithosis to humans (CDC, 2000) and gulls are known vectors of bacteria such as *Bacillus* sp., *Clostridium* sp., *Escherichia coli*, *Listeria* and *Salmonella* spp. that cause enteric diseases in humans (Belant, 1997). Many of these diseases can be transmitted to humans through contamination of water sources via birds frequenting rubbish dumps and sewage works then defecating in reservoirs and on roofs that are used for rainwater collection (Smith, 1995). For example, a build up in faecal coliforms in Prospect River that posed a health risk to Sydney residents was linked to high numbers of Silver Gulls at the reservoir (Smith, 1991). Birds (especially gulls) have also been implicated in accelerated nutrient loading of water sources which can increase the growth of bacteria and other pathogens (Belant, 1997).

Ecological Impacts

Overabundant bird populations can put pressure on the ecosystem surrounding them in terms of increased pressure on their food source, damage or changes in local vegetation, displacement of other species from nesting sites, increased competition for food and predation of adult birds or chicks and eggs (Egan, 1990; Smith, 1992; 1995; Belant, 1997; Johnson *et al.,* 2000; Guillemette & Brousseau, 2001; Bomford & Sinclair, 2002; Temby, 2003; USDA, 2003; Martin & Dawes, 2005). In the Great Lakes region in the USA, Double-breasted Cormorant populations are increasing dramatically and have been linked with the decline of the smallmouth bass (*Micropterus dolomieu*) population (Johnson *et al.,* 2000; USDA, 2003). They have also devastated a number of islands in the region where they breed and roost, with their acidic droppings (USDA, 2003). Australian White Ibis have displaced other species from nesting sites while at the same time damaging trees through nesting (Martin & Dawes, 2005). Due to their aggressive and territorial nature, most gull species have a negative impact on other bird species. They steal food, predate other birds' chicks and eggs and displace other species from nesting sites (Smith, 1995; Belant, 1997; Guillemette & Brousseau, 2001). They can reduce the reproductive output of some smaller birds quite significantly. For example, in Canada, predation by large gulls (Herring and Great Black-backed Gulls) led to a complete collapse in breeding success in the Common Tern (*Sterna hirundo*), but their breeding success increased to 33% in years when gulls were culled (Guillemette & Brousseau, 2001). In Australia, Silver Gulls predate on the eggs and chicks of Banded Stilts (*Cladorynchus leucocephalus*) and Little Terns (*Sterna albifrons*), reducing their reproductive output significantly (Egan, 1990; Smith, 1992; 1995). They have also negatively impacted the habitat on breeding islands, such as the Five Islands off Wollongong, where the largest island is now completely covered in Kikuyu grass which the gulls have introduced to the island. This makes it almost impenetrable for burrowing species such as shearwaters (*Puffinus* sp.) and Little Penguins (*Eudyptula minor*), which can get entangled in the runners and perish (Smith, 1995). Silver Gulls can also cause or exacerbate weed problems by the regurgitation of the seeds of weed species such as African Box-thorn (*Lycium ferocissimum*) and Mirror-bush (*Coprosma repens*) (Temby, 2003) and other native bird species are vectors for weeds such as Bridal Creeper (*Asparagus asparagoides*), olives and *Lantana camara* (Bomford & Sinclair, 2002).

Economic costs to agriculture and aquaculture

The economic costs of bird-aquaculture interactions have been discussed above and similar interactions occur in agriculture, although the emphasis of this chapter is on coastal birds so this is only briefly mentioned. Blackbirds (*Agelaius phoeniceus*, *Quiscalus* sp., *Molothrus ater*, *Euphagus* sp., *Turdus* sp., *Xanthocephalus xanthocephalus*), gulls, geese (*Anser* sp., *Branta* sp.), crows (*Corvus* sp.), lorikeets

(*Trichoglossus* sp.), corellas (*Cacatua* sp.) and other birds can cause severe damage to a host of agricultural crops including sunflowers, rice, corn, wheat, fruit and nuts (DAFF, 1997; Bomford & Sinclair, 2002; USDA, 2003). They damage the crops by eating the produce, trampling the crops and contaminating the fields with their droppings (DAFF, 1997; Bomford & Sinclair, 2002; USDA, 2003). Vultures (*Coragyps atratus, Cathartes aura*), ravens (*Corvus* sp.) and crows can attack livestock, especially newborns and mothers giving birth (Bomford & Sinclair, 2002; USDA, 2003), and starlings (*Sturnus vulgaris*) can adversely affect milk production at dairies by competing with the cows for food and by contaminating their feed with excrement (USDA, 2003). Gulls have also been reported competing with agricultural and zoo animals for food (Belant, 1997) and Silver Gulls can frequent agricultural fields in search of food such as ploughed worms and grain (Smith, 1995).

General Nuisance

As increased urbanization leads to a reduction in wildlife habitat some wildlife populations expand into urban areas and become overabundant and can cause millions of dollars worth of damage. Roof nesting and roosting by birds causes structural damage to buildings through them trying to gain entry (USDA, 2003), or by the build up of nesting material, regurgitated matter, feathers and faeces which can block gutters and reduce the life span of roofing material (Belant 1997; Bomford & Sinclair, 2002; Temby, 2003). Excrement from roosting birds can corrode machinery and car paint, cause severe odours, and create slippery conditions on walkways and pavements (Bomford & Sinclair, 2002; USDA, 2003; Temby, 2003; 2004). Cosmetic damage to statues, buildings, parks, beaches, and golf courses can occur from overgrazing, trampling and defecating by nuisance birds such as Canada Geese (*Branta canadensis*), feral pigeons, starlings and gulls (Christens *et al.*, 1995;

Belant, 1997; USDA, 2003). Many gull species have been observed stealing food from patrons at outdoor restaurants, frightening tourists and fouling public tables and benches (Smith, 1995; Belant, 1997).

Aggressive behaviour during nesting can also cause problems as nesting birds can be territorial and may cause physical injury to humans. Gulls nesting on roofs can harass personnel, swooping and defecating on them (Belant, 1997). Nesting Canada Geese and Australian Magpie (*Cracticus tibicen*) can be very aggressive with reports of people being injured by them (Bomford & Sinclair, 2002; USDA, 2003).

In Port Lincoln, South Australia, aquaculture is a major contributor to the local economy. Species such as Yellowtail Kingfish (*Seriola lalandi*), Greenlip Abalone (*Haliotis laevigata*), Blue Mussels (*Mytilus edulis*) and Southern Bluefin Tuna are farmed. Being a coastal town, many species of waterbirds, shorebirds and seabirds frequent the area, meaning an interaction between the two is inevitable.

1.6 The Southern Bluefin Tuna Industry in Port Lincoln

1.6.1 The Species

Southern Bluefin Tuna (*Thunnus maccoyii*) (SBT) are large, fast, pelagic fish found throughout the southern hemisphere mainly in waters between 30º S and 50ºS (Love & Langenkamp, 2003). They breed in the warm waters of the Indian Ocean south-west of Java, and spawn from September to March (PIRSA, 2000; Love & Langenkamp, 2003). The juveniles migrate south down the west coast of Australia and during the summer months, congregate near the surface in the coastal waters off the southern coast (PIRSA, 2000; Love & Langenkamp, 2003). They then move into the South Pacific Ocean and disperse to the Southern Ocean, the South Atlantic Ocean and back into the Indian Ocean (PIRSA, 2000; Love & Langenkamp, 2003). Once they reach maturity (9-11 years of age), they seek out deeper waters and are pelagic predators throughout the southern oceans of the world (PIRSA, 2000).

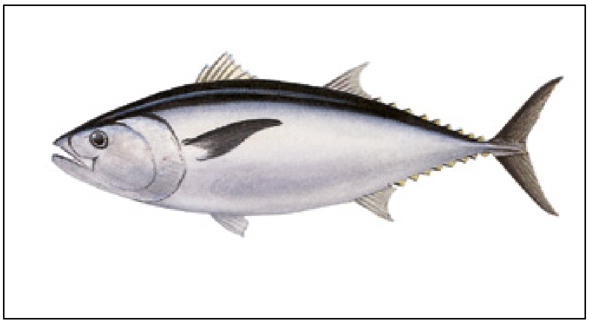

Figure 1.1: Southern Bluefin Tuna (*Thunnus maccoyii*) (source: Fishonline, 2003).

1.6.2 The Industry

Southern Bluefin Tuna farming began in 1991 as a result of a declining wild fishery, and a reduction in tuna supply prompted a move away from canning the product to a strategy of value-adding through farming (PIRSA, 2000; Love & Langenkamp, 2003; Aquafin CRC, 2006). SBT have been caught in the waters of the Great Australian Bight for several decades and were traditionally caught in their thousands to be canned as a low-cost product (PIRSA, 2000). The Australian catch peaked in 1982 at 21,500 tonnes, however, quotas were introduced after the formation of the International Commission for the Conservation of Southern Bluefin Tuna (CCSBT) in 1984 (Aquafin CRC, 2006). Quotas rapidly reduced from 14,500 tonnes in the mid 1980s, to 6,250 tonnes in 1988 and then to the current level of 5,265 tonnes in 1989 (Love & Langenkamp, 2003).

The SBT farming industry has grown to become the single most valuable sector of Australia’s aquaculture industry and the third highest by value edible fisheries export commodity (PIRSA, 2000; Aquafin CRC, 2006; ABARE, 2007). Almost 100% of the SBT is exported to Japan for the sashimi market, through frozen or freshly chilled product and is usually sold direct, but is also auctioned (Love & Langenkamp, 2003). It may reach prices of between AU$30 to $45 a kilogram (PIRSA, 2000), although exchange rate movements and competition from Northern Bluefin Tuna (*Thunnus thynnus*) farmed in the Mediterranean and Mexico have reduced the price received by Australian producers in the Japanese market (ABARE, 2007). The value of the industry hit its peak in the 2002/2003 financial year at AU$267 million (for 7763 t). However, due to depreciation in the yen and competition in the market, the 2004/2005 ($140 million, 7458 t) and 2005/2006 ($156 million, 8806 t) financial years were nowhere near as successful (ABARE, 2007). The variation in tonnage produced per financial year reflects fluctuations in the Japanese market, leading to tuna being held in pontoons later in the season, waiting for a better price, and thus fish farmed in one year may be included in the financial statement for the following year.

1.6.3 Production

Juvenile fish (15-25 kg) are caught from December to March from the continental shelf in the Great Australian Bight. The schools are located with a spotter plane, kept at the surface by baitfish fed out of a chumming boat and caught by encircling the school with a purse seine net (Love & Langenkamp, 2003; Aquafin CRC, 2006). The tuna are then transferred into a specialised tow pontoon, and towed to the growout farms near Port Lincoln at a steady pace of 1 to 2 knots, reaching the farms after about 2 weeks (PIRSA, 2000). On arrival at the farm sites, the tuna are transferred into the 30-50 m diameter circular growout pontoons (PIRSA, 2000; Aquafin CRC, 2006). The nets are 12-20 m deep and at least 5m above the seafloor (PIRSA, 2000).

The pontoon supports an inner net that holds the tuna and sometimes an outer net that deters predators. A standard pontoon holds up to 2,000 tuna, depending on its diameter and the maximum stocking rate allowed under the aquaculture licence (PIRSA, 2000). Approximately 60,000 tonnes of baitfish are used by the industry per annum to feed the SBT utilising two main methods, shovel and frozen block (§2.2.1 for a full description).

An average tuna increases in weight by 10-20 kg during the farming process (Love & Langenkamp, 2003). Once the tuna reach a marketable size and fatness (condition) (after 3-4 months), they are harvested on an almost daily basis. They are killed quickly with a metal spike through the brain, bled, gilled and gutted and then placed in an ice-brine mixture to rapidly lower body temperature to help preserve freshness (PIRSA, 2000).

Research into the hatchery production of tuna has been underway for a number of years. In 2002 a Japanese laboratory successfully reared Northern Bluefin Tuna from eggs, which developed into mature fish that spawned eggs, hatching a new generation (Love & Langenkamp, 2003). In March, 2008, Clean Seas Tuna Limited in South Australia successfully hatched Southern Bluefin Tuna larvae (Clean Seas Tuna Limited, 2008[a]) and in July 2008, Northern (Atlantic) Bluefin Tuna spawned successfully in Europe, using the same artificial breeding regime (Clean Seas Tuna Limited, 2008[b]), in an effort to close the lifecycle of these species and to reduce pressures on wild stocks and increase supply (Clean Seas Tuna Limited, 2008[a]; 2008[b]).

1.7 Seabirds Interacting with the Southern Bluefin Tuna Industry

Seabirds interact with the SBT Industry in the Port Lincoln area, scavenging the baitfish that are fed to the tuna (Harrison, 2003). The seabirds are naturally attracted to the offshore farm sites as they are within their natural foraging area. In addition, the ~130 pontoons are highly visible and are stationary throughout the entire farming season. The feed boats are also highly visible and the shovel feed method is visually attractive to the seabirds.

Seabirds interact with the industry in a number of ways:

1. They roost on the pontoons.
2. They are attracted to and forage for the fish that are attracted to the farms.
3. They scavenge the baitfish fed to the tuna.

There are several seabird species that frequent the tuna farms including Crested Terns (*Sterna bergii*), Pacific Gulls (*Larus pacificus*) and Short-tailed Shearwaters (*Puffinus tenuirostris*), however, the Silver Gull is the seabird in the highest abundance and causing the most concern.

1.7.1 The Silver Gull (*Larus novaehollandiae*)

The Silver Gull is one of Australia's best known seabirds and it is a protected species throughout Australia under the National Parks and Wildlife Act 1974 (Smith, 1995). They are mainly coastal, particularly in and around urban settlement, but are also found along rivers, inland waters and some inland towns (Smith, 1995; Higgins & Davies, 1996). Sub species of the Silver Gull are found in New Zealand (Red Billed Gull, *L. n. scopulinus*) and New Caledonia (*L. n. forsteri*) with *L. n. forsteri* also inhabiting the northern coast of Australia (Smith, 1995). *L. n. novaehollandiae* is present elsewhere throughout the Australian continent from Western Australia to Queensland with a geographical variation in size such that Western Australian gulls are larger than those in the east, and gulls from New South Wales are larger than those from Tasmania, implying a geographical separation of the population into three groups (Smith, 1995).

It should be noted that the genus of the Silver Gull was reclassified from *Larus* to *Chroicocephalus* in the 2008 publication by Christidis and Boles, however, as this occurred after the completion of this research, the genus *Larus* will be used throughout this thesis.

Length 36-44cm
Wingspan 91-96cm
Weight 265-315g.
Sexes similar, males have a slightly wider bill than females. Adult plumage white with grey back, black wing and tail tips. Eyes are white with red eye ring, bill and legs bright red. Juveniles up to one year of age have mottled brown and grey upperparts with black-brown eyes, bills and legs (Higgins & Davies, 1996).

Figure 1.2: A juvenile (left) and adult (right) Silver Gull.

Silver Gulls roost on islands, beaches, sandbanks, mudflats, sea walls, pipelines, jetties, wharves, pylons, disused ship hulks, swimming enclosures and buildings. Every evening gulls fly to favoured locations to roost and prior to dawn leave their roost for feeding locations, returning in the late afternoon. In some places these flights can be over considerable distances such as 70 km between the Big Island breeding colony near Wollongong to Sydney (Smith & Carlile, 1992).

Silver Gulls are opportunistic scavengers exploiting a wide variety of food sources. They feed on natural food such as insects, worms (in ploughed fields), berries, marine invertebrates and fish (Higgins & Davies, 1996). However, they have become very reliant on humans for food and are generally adept at taking advantage of artificially enhanced food supplies around urban centres, particularly at waste disposal depots, parks, sewage outfalls, fishing boats and fish processing plants and scavenging from humans (Smith *et al.*, 1991; Wood, 1991; Smith & Carlile, 1992; Higgins & Davies, 1996; Svane, 2005). The sight of a gull with food will attract all other gulls close by (Higgins & Davies, 1996).

Silver Gulls are opportunistic, communal breeders and have non-specific nesting requirements, exploiting a wide range of habitats including offshore islands, roofs, boats, disused wharves and inland on trees, stumps and islands on inland waterways (Smith & Carlile, 1993; Smith, 1995). The nest is a shallow cup of fine plant material upon a platform of available material (Frith, 1976). Breeding typically occurs over a discrete period of several months, which varies across regions, however it can be year round if food is available (Smith, 1995).

Silver Gulls can breed from two years of age, but generally breed from three years old (Smith, 1995). Eggs colour can range from dark green, pale olive, light brown, blue green, pinkish to white with a darker mottled coloured on top (Higgins & Davies, 1996) and are laid up to 19 days after the nesting territory is established. Clutch size is usually 1-3 and incubation is shared by the parents and takes from 19 to 29 days (Smith, 1995; Higgins & Davies, 1996). Chicks move out of the nest at about one week of age, they are fed by the parents for up to six weeks and fledge at about 6-7 weeks (Smith, 1995). Fledged young disperse in their first year, but usually return to the natal colony.

In many parts of Australia, Silver Gull numbers have increased enormously over the past 60 years and have generally accompanied increases in human populations. As mentioned above, on Big Island, off Wollongong, NSW, breeding numbers expanded from a few pairs prior to 1940 to 51,500 pairs in 1978 (Smith, 1995). A similar increase was seen on Mud Island in Port Phillip Bay, Melbourne, Vic, where numbers rose from five pairs in 1959 to 50,000 pairs in 1986 (Menkhorst *et al.*, 1988). Silver Gulls are also becoming more abundant where they previously did not occur, such as Darwin and islands along the Great Barrier Reef (Smith, 1995). The population increases have mainly been attributed to their opportunistic feeding behaviour and abundant food availability (Smith, 1995; Higgins & Davies, 1996). This has enabled many populations to lengthen their breeding season which presumably resulted in higher fecundity and greater survival (Smith, 1995; Higgins & Davies, 1996). The resulting overabundant gull populations can cause conflicts with humans and wildlife with the most problematic being bird strikes, ecological impacts and nuisance issues.

The Silver Gull population in the Port Lincoln area increased from around 3,300 nesting pairs in 1999 (Farlam, unpublished data) (determined by counting occupied nests) to 10,300 nesting pairs in 2003 (Harrison, 2003) (determined by counting occupied and new nests within quadrats (extrapolation) or by counting pairs from a boat). These gulls frequent the tuna farms for food and to scavenge the high quality baitfish fed to the tuna. Although little quantification has been undertaken on the actual total feed loss to the seabirds, it is known that in 2003, one company lost an estimated 2.3% of its feed to seabirds (Harrison, 2003). This was determined by observing the distribution of food and counting what was consumed by birds at set intervals. This company had about 7% of the tuna quota, or fed out ~7% of the 50,000 tonnes of total baitfish fed out that year. The 2.3% of baitfish scavenged equated to approximately 70 tonnes of feed lost to seabirds. Around 90% of the feed lost was taken by Silver Gulls, with Crested Terns, Pacific Gulls and Short-tailed Shearwaters consuming the other 10% (Harrison, 2003).

The opportunistic nature of Silver Gulls has allowed them to take advantage of this food source. This is evident in the protracted breeding season of this population, which has changed to encompass the tuna farming season. Before tuna farming was initiated (prior to 1991), the breeding season of Silver Gulls in the Port Lincoln and lower Eyre Peninsula region ran from May to September (1987-1989) (Farlam, unpublished data). However, for the Port Lincoln population this changed from April-November in 1998-2000 (Farlam, unpublished data). During the 2003 season, this changed again to March-October (Harrison, 2003) and coincided with most of the tuna farming season (February-September/October). In 2003 the Port Lincoln breeding season began 6-7 months earlier than any other known colony in the State and was also a longer breeding period than those colonies.

Apart from the protracted breeding season, another reason the population may be increasing is a higher reproductive output. The clutch size of this population of gulls was found to be almost twice that of the reference population of gulls in the Coorong which mainly had access to natural food (Harrison, 2003). However, egg weight was significantly smaller in the Port Lincoln population (Harrison, 2003). Recruitment of individuals from other Silver Gull colonies around the state could also potentially increase the population, as the high quality food is available to support them over most of the year.

Thus it is believed that the SBT industry is likely to be having a direct positive effect on the reproductive output of these gulls through the availability of this high quality food. As the food source is readily accessible, potentially all breeding Silver Gulls could have access to it, meaning the reproductive success of the entire population should be high (compared to a site with little to no access to human derived food). This diet high in fish should lead to an increase in female body condition, egg size, clutch size, chick size, chick survival and fledging success (Annett & Pierotti, 1989; 1999).

While the dynamics of the breeding Silver Gull population seem to have been directly influenced by the tuna season, the dynamics of gull numbers in Port Lincoln itself also seem to be affected. While most other increasing Silver Gull populations rely heavily on human refuse, there is little evidence for this in Port Lincoln during the tuna season, however numbers do increase over the off-season. During the tuna season there are few Silver Gulls in the urban areas, but this increases as harvest progresses from about July onwards and only then do the gulls begin to rely on the refuse dump (Harrison, 2003). The end of the gulls' breeding season in October coincides with the end of the tuna season. The end of feeding at the pontoons means many gulls and their newly fledged chicks need to find new sources of food. These birds must either forage for natural food, or move to Port Lincoln to exploit other anthropogenic sources of food which leads to two problems. First, foraging gulls may have a severe impact on other birds in the area through klepto-parasitism and predation. This impact is exacerbated by the timing coinciding with the breeding season of many seabirds that Silver Gulls are known to predate. The gulls mainly take the eggs and chicks which has a considerable impact on the reproductive output of these species, especially of vulnerable species such as Little Terns (*Sterna albifrons*) (Egan, 1990) and specialist breeders such as Banded Stilts (*Cladorynchus leucocephalus*) which have specific, predictable breeding requirements (Baxter, 2003). Second, the increase in Silver Gull abundance in Port Lincoln is at the height of the tourist season (Harrison, 2003). These gulls frequent the garbage tip, eateries, the foreshore, beaches and other places where they might scavenge food. Thus the influx of gulls into Port Lincoln causes management, health and nuisance problems, and they are unpopular with the general public.

Unlike most bird-aquaculture interactions, where the cultured fish is usually predated, this is not possible with SBT as they are much too large (>16kg) to be taken. In addition, where there have been published reports of birds taking aquaculture feed, this has always been of pellets, but pellets are not widely used in SBT farming. Finally, published results indicate terrestrial and diving birds cause the majority of problems in aquaculture, but in this situation, seabirds, in particular, gulls cause the most conflict. So in many ways, the Port Lincoln situation is most similar to the interactions reported for seabird and fisheries discards because of the concentration of large quantities of fish of a size preferred by seabirds that float or sink slowly, and hence are easily accessible. In addition, seabirds reported to feed and rely on discards are similar to the species found feeding at the finfish pontoons in Port Lincoln with Crested Terns and Silver Gulls utilising discards in Australian waters (Wood, 1991; Blaber *et al*., 1995; Svane, 2005).

Limited data exist on this interaction between seabirds and SBT aquaculture, apart from the results reported in Harrison (2003). However, the results from the one SBT company used in that study suggest that several seabird species are interacting with the industry, and feed loss over the whole industry is potentially quite high. With the value of the tuna industry decreasing and the Silver Gull population increasing, this interaction has the potential to create conflict between an important regional industry and the broader community. Thus, additional research is required to gain a better understanding of the interactions, to quantify the nature, extent and consequences of each of these issues and to search for and provide solutions to the problems including potential mitigation measures to decrease the interactions.

1.8 Thesis Structure, Project Aims and Hypotheses

1.8.1 Thesis Structure

There are nine chapters in this thesis.

Chapter 1 is a General Introduction and review of relevant literature such as bird-aquaculture, bird – fisheries interactions, the effect of human refuse on bird populations, the possible ways that growth in bird numbers can impact on the environment and on human activities, an overview of the SBT industry and how seabirds interact with it, information on the Silver Gull and project aims and hypotheses.

Chapter 2 is a detailed description of the General Materials and Methods as several chapters utilise the same methodology and only brief descriptions are provided in the subsequent chapters. This Chapter describes each of the sites and methodologies including a description of tuna feeding, methods to calculate feed loss to scavenging birds, seabird abundance, reproductive parameters, banding birds and statistical analysis.

Chapter 3 is the first results chapter and details the observations and data collected on seabirds scavenging at tuna farms. It looks at feed loss using different feeding regimes, baitfish size, and individual seabird species scavenging rates and details the accuracy of the feed loss method using calibration (comparing real time data to video tape data). It also details seabird abundance at tuna farms, comparing different feeding methods.

Chapter 4 details the analysis of both the nesting Port Lincoln and reference Silver Gull diet, mainly through collection of regurgitated pellets from within the nesting colony and subsequent identification of prey remains.

Chapter 5 details the observation on the population dynamics of breeding and non breeding Silver Gulls in the Port Lincoln area. It details observations on the abundance of Silver Gulls at seven sites across Port Lincoln throughout the year, but also includes details on breeding Silver Gull abundance on the nesting colonies.

Chapter 6 details the results of the reproductive output of Port Lincoln Silver Gulls compared with a reference population of Silver Gulls. The parameters used include breeding season length, clutch size, egg volume, hatching success and fledging success.

Chapter 7 describes the scaring device trial undertaken on research SBT farms. This trial was undertaken to determine whether simple scaring devices could reduce the amount of feed scavenged by birds whilst shovel feeding.

Chapter 8 details the results from the Silver Gull egg oiling trial undertaken in 2006 to determine the efficacy of this method in reducing the reproductive output of Silver Gulls. Parameters monitored include hatching success, incubation period and relaying rate.

Chapter 9 is a General Discussion and an overview of the results obtained throughout the thesis. It links the results of all the chapters together, describes future research that could be undertaken and finishes with a conclusion.

1.8.2 Aims

The aims of this project were:

1. To quantify feed loss to Silver Gulls from the SBT industry over three years using as many companies as possible (Ch3).
2. To calibrate or assess the accuracy of the feed loss quantification technique (Ch3).
3. To quantify feed loss to other seabirds (Ch3).
4. To compare feed losses from the different feeding methods used by the industry (Ch3).
5. To assess if the seabirds show any preference for the different baitfish species used by the industry (Ch3).
6. To compare seabird abundances at tuna farms using different feeding methods (Ch3).
7. To identify the best feed method for the industry in terms of reducing feed loss to seabirds (Ch3).
8. To compare the diet of the Port Lincoln Silver Gulls to those of reference sites (Ch4).

9. To monitor the size of the breeding population of Silver Gulls in Port Lincoln over several years (Ch5).
10. To monitor the population dynamics of the Port Lincoln Silver Gull population (Ch5).
11. To assess several reproductive output parameters of the Silver Gull population in Port Lincoln and compare these to reference populations (Ch6).
12. To test the efficacy of scaring devices in reducing feed losses to seabirds (Ch7).
13. To test egg oiling as a method to control Silver Gull populations (Ch8).

1.8.3 Hypotheses

Chapter 3:

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

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

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: 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.

Chapter 4:

H0: The diet of the nesting Port Lincoln gulls will not be different to that of the reference gulls.

HA: The diet of the nesting Port Lincoln Silver Gulls will be significantly different to that of the reference site gulls.

Chapter 5:

H0: There will be no change in nesting Silver Gull abundance in the Port Lincoln area over time.

HA: There will be a change in nesting Silver Gull abundance in the Port Lincoln area over time.

H0: There will be no seasonal pattern of Silver Gull abundance in the City of Port Lincoln over each year in relation to activities in the tuna industry.

HA: There will be a seasonal pattern of Silver Gull abundance in the City of Port Lincoln over each year in relation to activities in the tuna industry.

Chapter 6:

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

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

Chapter 7:

H0: The use of scaring devices during shovel feeding will have no effect on the amount of feed scavenged by seabirds.

HA: The use of a scaring device whilst shovel feeding will change the amount of feed scavenged by seabirds.

H0: The type of deterrent (visual, physical, audible) will have no impact on the amount of feed scavenged by seabirds.

HA: The type of deterrent (visual, physical, audible) will have an impact on the amount of feed scavenged by seabirds.

Chapter 8:

H0: Egg oiling will have no impact on the hatching success of Silver Gull eggs.

HA: It is predicted that egg oiling will change the hatching success of Silver Gull eggs.

H0: Treating the eggs once or twice with oil will produce the same results.

HA: Treating the eggs once or twice with oil will produce different results.

H0: Egg oiling will have no impact on early clutch loss or relaying rate.

HA: There will be a change in early clutch loss and relaying rate for treatment (oiled) eggs in comparison to those that had eggs assigned the control treatment (no treatment).

H0: Egg oiling will not alter the period parent gulls incubate eggs.

HA: There will be a change in incubation period for treatment vs. control eggs.

1.9 Constraints to the Research

There were many constraints that limited the way I could carry out observations and experiments and this resulted in experimental designs that were not always statistically balanced, observation schedules that were sometimes infrequent and non-randomised, and posing of questions that were industry-driven rather than scientifically-driven.

This research was performed under the Aquafin CRC, a highly successful CRC that focussed mainly on applied industry issues – tuna nutrition, disease, product quality, metabolic physiology; the impacts of tuna farming on the marine environment (dissolved and particulate nutrient releases and dispersion, fate of unconsumed tuna feed below pontoons); and the impact of the farming environment on tuna (water movement, dissolved oxygen, algal blooms, net fouling). However, whilst this project topic clearly fitted into the scope of the CRC, perhaps because it was ‘out of the water’ and multi-factorial in nature (i.e. the industry could argue the seabirds were present before tuna farming started), the industry considered it ‘peripheral’ and therefore it did not get the same attention as most other topics.

The overarching constraints of this project were logistics, finance and weather. The majority of my research was based on the SBT farms and offshore breeding islands, which both required access to a boat. There was only a small amount of money to put towards use of the 8m Flinders University boat “*Tolero*”, and this was utilised to gain access to the breeding colonies. As the Silver Gulls breed for 10 months of the year and I had a limited budget, I could not access the islands as often as I would have liked. In addition, weather conditions throughout the majority of the breeding season (end January – start October) were relatively rough, therefore, I needed to wait for calmer weather to access the breeding colonies and consequently it was not always possible to keep a strict observation schedule.

To gain the ‘whole of industry perspective’ that was needed to operate within the Aquafin CRC, I needed to work with, and observe, as many tuna companies as possible. Over the three years of field work I obtained data from eight of the thirteen possible companies. Whilst this number was not as high as it should have been, it was as high as I could make it. Some tuna farming companies were highly sceptical and dismissive of my project due to the contentious nature of the issue, and so I was not able to undertake observations from their boats. Similarly, had I used the University boat to try to approach the pontoon to make observations I would not have had feed information (baitfish species, ratio, quantities shovelled vs frozen block) but I would have potentially jeopardised cooperation between those companies and other aspects of the broader CRC research program. On the other hand, if I had only used one or two companies and carried out more balanced trials (eg permitting evaluation of different weather conditions), the industry would criticise my data because it was not representative enough.

Even with those 8 companies that did let me make my observations, many aspects were largely beyond my control: I could not dictate what order the pontoons were fed in, or what feeding method the company utilised, which led to non-random sampling, on some companies' farms I observed both morning and afternoon feeds, whilst on others, I only observed one or the other feeding event. This meant that the data I collected were complex as the majority of the 8 companies work independently of each other and therefore were not uniform in terms of feeding regime, location of lease, and attitude towards environmental matters.

This section will hopefully explain why elements of the subsequent Chapters (applied rather than academic focus, sampling frequency, sampling order, statistical robustness etc.) are as they appear. Acknowledgment, but not apology, is given that this detracts from the flow and structure of the thesis.