Impact Assessment of aquaculture on seabird communities of the Abrolhos Islands, to support the Mid-West Aquaculture Development Zone proposal.

DoF21/2013

<u>Final Report</u>

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1. Introduction

1.1 Background

In June 2014 The Department of Fisheries (DoF) engaged Halfmoon Biosciences to undertake an environmental impact assessment (EIA) of potential interactions between proposed marine finfish aquaculture and seabird communities including their marine ecosystems and island habitats. The investigation focussed on breeding colonies found in the vicinity of the Pelsaert Group and Easter Group of the Houtman Abrolhos Islands adjacent to areas being assessed as designated finfish aquaculture zones. The EIA is required to inform a Public Environmental Review (PER) for the Department's Mid-West Aquaculture Development Zone (MWADZ) proposal to be assessed by the WA Environmental Protection Authority.

1.2 Impact assessment of aquaculture on seabird communities

The offshore production of marine finfish is one of the aquaculture sectors considered most likely to provide large scale industry development in Western Australia. The Department of Fisheries has identified several advantages associated with creating aquaculture management zones to reduce conflict with other users of the marine environment and to streamline the environmental approvals process for entrants into the sea cage finfish aquaculture industry.

Two potential Mid-West aquaculture areas at the Abrolhos Islands were identified as options for evaluation during the data gathering stage, one north of the Pelsaert Group and the other east of the Easter Group.

In May 2013, the Department referred the Mid-West Aquaculture Development Zone (the Zone) proposal to the Office of the Environmental Protection Authority (OEPA) for assessment as a strategic proposal, and the level of assessment was set at Public Environmental Review (PER). The proposed area (Zone) will be established within the Fish Habitat Protection Area of the Houtman Abrolhos Islands (Refer to Attachment 1 – Zone study area). Some environmental approval process steps were previously completed for an existing finfish aquaculture site within one potential Zone, north of the Pelsaert Group of the Abrolhos Islands (EPA, 2003).

The Commonwealth has decided not to conduct a joint assessment of the aquaculture Zone but may assess fish-farming proposals within them should they eventuate. There are numerous potential wildlife related triggers for EPBC Act at the Abrolhos. The matters of national significance include threatened species, migratory species, petrels and cetaceans.

One of the Department's objectives is to protect the seabird populations and island ecosystems within the Abrolhos Islands Ministerial Reserve (Abrolhos Islands Management Plan). To meet this objective, the cause / effect relationships that could lead to changes to population levels and ecological relationships must be understood. This includes flow-on risk from changes to the function of terrestrial ecosystems on the seabird breeding islands. The Department has requested an investigation into the current status of seabirds on the

Abrolhos Islands and potential interactions between seabirds and finfish aquaculture. This work will contribute to the environmental and technical field studies that will inform a Management Framework, including a Management Policy for aquaculture operations within the Zone.

The aims of this study were:

- The assessment of potential interactions between proposed marine finfish aquaculture and seabird communities and their habitats found in the vicinity of the Pelsaert Group and Easter Group of the Houtman Abrolhos Islands.

- Provide a summary of the current knowledge of seabirds, key seabird species and stressor-response relationships between seabirds and potential aquaculture projects, including identification of, and baseline monitoring of previously identified high risk increaser-species (e.g. Silver Gulls *Chroicocephalus novaehollandiae*, Pacific Gulls *Larus pacificus* and Pied Cormorants *Phalacrocorax varius*).

- Identify significant potential interactions between seabirds and aquaculture and provide an assessment of the ecological risk arising from them.

- Develop a basic conceptual model of ecological cause-effect pathways involving high risk species (e.g. Silver Gulls, Pacific Gulls and Pied Cormorants), that may lead to ecological change.

- Develop a practical monitoring program to inform management to minimise any potential impacts of the interactions between fish-farming operations and seabirds,

- Provide advice on additional mitigation measures and appropriate operational management strategies to mitigate adverse interactions with seabirds from any residual risks (not treated by practices required by the Department).

1.3 Review of breeding seabirds on potentially impacted islands of the Houtman Abrolhos

1.3.1 Birds of the Houtman Abrolhos.

The Houtman Abrolhos is the most significant seabird breeding location in the eastern Indian Ocean. Eighty percent (80%) of Brown (Common) Noddies *Anous stolidus*, 40% of Sooty Terns *Onychoprion fuscata* and all the Lesser Noddies *Anous tenuirostris melanops* found in Australia nest at the Houtman Abrolhos (Ross *et al.* 1995). It also contains the largest breeding colonies in Western Australia of Wedge-tailed Shearwaters *Ardenna pacifica*, Little Shearwaters *Puffinus assimilis*, White-faced Storm Petrels *Pelagodroma marina*, White-bellied Sea Eagles *Haliaeetus leucogaster*, Osprey *Pandion haliaetus*, Caspian Terns *Hydroprogne caspia*, Crested Terns *Thalasseus bergii*, Roseate Terns *Sterna dougalli* and Fairy Terns *Sterna nereis* (Storr *et al.* 1986, Surman and Nicholson 2009a). The Houtman Abrolhos also represents the northernmost breeding islands for both the Little Shearwater and White-faced Storm Petrel.

Within the Pelsaert and Easter Groups, seventeen (17) species have been confirmed as breeding regularly. These are the White-bellied Sea Eagle, Osprey, Wedge-tailed Shearwater, Little Shearwater and White-faced Storm Petrel, Pacific Gull, Silver Gull, Caspian Tern, Crested Tern, Bridled Tern *Onychoprion anaethetus*, Roseate Tern, Fairy Tern, Brown Noddy, Lesser Noddy, Eastern Reef Egret *Egreta sacra*, Pied Oystercatcher *Haematopus longirostris*, and Pied Cormorant (Surman and Nicholson 2009a).

1.3.2 Potential Increaser Seabird Species

Previous experience indicates that several species of seabird populations may have adverse interactions with the development of sea cage, finfish aquaculture at the Houtman Abrolhos. However, both the experience from fish-farming elsewhere in Australia and the local foraging information indicate three species have at least moderate risk. These are the two gull species (Pacific Gull and Silver Gull) and the Pied Cormorant. These three species would be able to take advantage of activities associated with humans that result in a food (energy) subsidy particularly during periods when food availability is limiting (Harris and Wanless, 1997, Montevecchi 2002). Additional food resources can result in increased breeding effort and success leading to expanding populations, with potential detrimental impacts on other seabirds and island ecosystems in the area.

Approximately 356 pairs of Silver Gulls were recorded nesting at the Houtman Abrolhos on 25 islands during an island wide survey conducted in December 2006 (Surman and Nicholson 2009a). The largest colonies were observed on Long Island in the Wallabi Group (142 pairs), Pelsaert Island (43), Leo's Island (34) and Wooded Island (33). During previous studies in relation to finfish aquaculture (Surman and Nicholson 2008, 2009b) there were found to be significant differences in the size of Silver Gull colonies in spring/summer and autumn. For example, there were approximately 41 pairs nesting on Post Office Island in the autumn, compared with only 2 pairs during the summer period. In May 2007, on Long Island in the Wallabi Group, there were at least 142 pairs of Silver Gulls attending nests, whereas in December 2006 only three nests were active (Surman, *pers. obs*). The larger colony sizes in May were attributed to increased food availability to this species during the presence of Rock-lobster fishers during the March 15-June 30 rock lobster fishing season. The A Zone rock lobster fishing season was recently removed.

Adult Silver Gulls are only incapable of reproduction for about 10 weeks a year during the moult period when the gonads regress to a resting state. This non-reproductive / moult period is triggered by increasing day length in late spring or early summer. After this period the gonads reactivate and breeding can resume at any time if there are sufficient resources available for the females to produce their eggs (Dunlop 1987). The timing of the onset of breeding varies from location to location. At some colonies breeding can occur continuously for 9-10 months with females capable of producing multiple clutches and some pairs raising two broods per season (Wooller & Dunlop 1979, Wooller & Dunlop 1981a). These aspects of breeding biology allow Silver Gulls to respond rapidly to seasonal changes in food availability. The massive increases in Silver Gull numbers at Port Lincoln was driven by increased food availability from finfish aquaculture, particularly the sardines fed to ranched Southern Blue-fin Tuna *Thunnus maccoyii* (Harrison 2010).

Pied Cormorant, Silver Gull and Pacific Gull populations at the Houtman Abrolhos are currently reliant upon natural food sources only. The establishment of a finfish farms in either of the proposed areas could potentially lead to in changes in the size of these species populations (or changes in colony location) that could result in increased competition with, or predation of other seabirds or alteration in breeding habitat (Surman 2004). Increases in the Pied Cormorant colonies and could enhance the mechanical and guano stress on the mangrove habitats. Comparable changes in island vegetation have been observed with increasing Pied Cormorant numbers off the Perth metropolitan region (Wooller & Dunlop 1981b). The increase in cormorants in this region is attributed to the eutrophication of the southern metropolitan coastal waters and Peel/Harvey Estuary.

1.3.3 Potential Adverse Interactions with Seabirds

Interactions which can have a detrimental impact upon seabirds can occur at the island breeding colony or whilst foraging at sea. Direct disturbance to colonies from human visitation can include trampling or exposure of nests, disorientation of nestlings, enhanced predation or kleptoparasitism and interruption to breeding or feeding behaviours. Adverse interactions while foraging may arise from attraction to, or avoidance of, vessels and marine infrastructure or disturbance to prey aggregations or associated predators and exposure to contaminants.

Direct interactions with finfish farming operations could include:

- Supplementary feeding from stock predation, fish food, waste material or food scraps
- Collisions with sea cages, other structures or vessels moored at night
- Attraction and disorientation due to inappropriate lighting on service vessels, pens or navigation markers at night
- Entanglement in cage mesh, predator nets or protective bird netting
- Attraction of prey to vessels or sea cages due to “FAD” effects.
- Attraction to the fish stock
- Use of vessel or sea cages as roosting sites

The location of the Pelsaert Group aquaculture zone is just 2km from Stick Island. There is a mixed colony of Little Shearwaters and White-faced Storm Petrels on Stick Island (Surman and Nicholson 2009a), and many Wedge-tailed Shearwaters use Middle Channel as a flight path back to their colonies on Pelsaert, Middle and Gun Islands from their foraging grounds (ibid). All these petrel species return to their colonies at night. The presence of a semi-permanently moored vessel could potentially impact upon individuals of these species through:

- Collision
- Light attraction
- Disorientation

Collision rates will be greatly increased by unmasked, bright lights.

These impacts may result in either injury or death. Also, birds found on the decks invariably regurgitate meals meant to be delivered to young at the nest, thereby depriving those nestlings of a single feed.

At certain times of year, fledgling shearwaters and storm petrels depart nesting grounds and head to sea in the darkness of pre-dawn. These young inexperienced birds orientate to light on the horizon and are particularly vulnerable to being attracted to lighting, becoming disorientated.

It is assumed that the food for the fingerlings raised in the cages will be pelletised, which will have negligible attractiveness to pursuit-diving seabirds such as Pied Cormorants and Wedge-tailed shearwaters. However, Pied Cormorants may be attracted to the cages to feed upon fingerlings themselves, and in doing so may attempt to reach fish through the mesh. This may present an entanglement issues for this species.

The management plan for the proposed fish farm would need to address these concerns with mitigation methods to address the potential for entanglement if Pied Cormorants are attracted to the cages to feed on fingerlings.

1.4 Assumptions about production systems utilized in fish-farming precincts

The scientific literature on marine wildlife interactions with sea-cage operations in Australia is limited. Most of the observations are either anecdotal or presumably in compliance monitoring reporting that is not available in the public domain. This lack of transparency would appear to be an issue in itself. A review of the environmental effects of fish-farming, including wildlife interactions, was done in New Zealand (Forrest *et al.* 2007) but the coverage on seabirds was speculative with no reference to structured observations.

During the early stages of the Atlantic Salmon *Salmo salar* sea-cage aquaculture in Tasmania problematic interactions were reported with New Zealand Fur Seals *Arctocephalus forsteri*, Silver Gulls, Water Rats *Hydromys chrysogaster*, Great Cormorants, *Phalacrocorax carbo* Black-faced Cormorants *Phalacrocorax fuscescens* and Sea-eagles (Pemberton *et al.* 1991). Of these only Silver Gulls, cormorants (mainly Pied Cormorants) and Sea-eagles (also Ospreys) are present at the Abrolhos Islands. The Australian Sealions *Neophoca cinerea* at the Abrolhos Islands may be attracted to the sea-cages if they are rewarded with feeding opportunities. In the Tasmanian operations the gulls targeted stock and feed from above the pens, sea-eagles attacked stock from above, whilst cormorants pursued stock from underwater through the mesh of the pen. Sea-eagles only attempted foraging over the large diameter pens. Since the 1990s predator and bird-nets, fur-seal barriers and other measures have been introduced into the Tasmanian salmon industry. However the outcomes of this have apparently not been scientifically assessed and reported in the public domain. It is assumed that best practice wildlife exclusion methods now used in Tasmania would be adopted at the Abrolhos from the outset.

At Southern Bluefin Tuna ranching pens at Port Lincoln the stock are still fed whole pilchards from defrosting frozen blocks, with some shovelling of fish to the pen surface to excite a feeding response. Silver Gulls scavenged an estimated 2.3% of feed from one operator. An estimated 790 tonnes of pilchards was taken by seabirds from all the tuna pens annually. This energy subsidy allowed the Silver Gull to expand its breeding season (now parallels the ranching season), increase their reproductive output (per pair) and exponentially increasing its local breeding population from 3 300 pairs in 1999 to 27 800 pairs in 2005 (Harrison 2010). The downstream ecological consequences on other species has not been assessed. Again it is assumed that best practice will be applied at the Abrolhos and feed will not be directly accessible to gulls or other seabirds.

The largest known impact of sea-cage aquaculture on Australian marine ecosystems resulted from two massive fish kill epidemics in pilchards caused by the introduction of a novel herpes virus via imported whole fish (sardine) feed at Port Lincoln in the 1990s (Whittington *et al.* 2008). This epidemic caused a major reduction in the pilchard stock and was known to impact several seabird species dependent on these forage fish including Little Penguins *Eudyptula minor* (Dann *et al*. 2000), Australasian Gannet *Morus serrator* (Bunce & Norman 2000) and Crested Terns (J.N. Dunlop *pers.obs*.). This event highlighted the importance of pathogen biosecurity for minimizing the ecological risks posed by open system sea-cage aquaculture. It is assumed that farmed stock will not be fed whole frozen fish and that the fishmeal in food pellets will be screened for microbes or sterilized. Under the management arrangements proposed for the mid-west aquaculture development zone, the use of pilchards and other wet (fresh or frozen) fish as stock feed will not be permitted. Only manufactured pellets will be used as stock feed.

The Department of Fisheries has provided a 'Representation of Aquaculture Operations' for the proposed mid-west aquaculture development zone. Whilst this appears to cover best-practice in marine finfish sea-cage operations it does not specifically mandate the mitigation measures required to minimise seabird (and other wildlife) interactions. The interaction between risks, mitigation measures and monitoring strategy will be dealt with in Section 4.

The Department's brief indicates that most previously developed mitigation methods to separate wildlife from stock, feed and hazards will be employed. The currently 'untreated' risks in the Departments brief appear to be the FAD affect, lights and feed drift through the cage mess. The latter potentially attracting seabirds, particularly cormorants, to aggregations of small wild fishes.

1.5 Threat Status

Components of the avifauna at the Houtman Abrolhos are protected under three National and State Acts; the Environment Protection and Biodiversity Conservation (EPBC) Act 1999, the Conservation and Land Management (CALM) Threatened and Priority Fauna Database and the Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014.

Migratory species are protected under the EPBC Act (1999), and are included in the Japan Australia Migratory Bird Agreement (JAMBA), the China Australia Migratory Bird Agreement (CAMBA) and the Republic of Korea-Australia Migratory Bird Agreement (ROKAMBA). Of these, all migratory waders recorded in Surman and Nicholson (2009a), as well as the Eastern Reef Egret and seabirds including the Bridled Tern, Caspian Tern, Crested Tern, Osprey and White-breasted Sea Eagle, are listed under migratory bird agreements with either Japan, China or Korea. Birds covered by these agreements are listed in Schedule 3 under the Wildlife Conservation Act 1950 (WA).

Eight bird species found at the Houtman Abrolhos are also listed under the CALM Threatened and Priority Fauna Database, although only one of these species, the Lesser Noddy, is likely to interact with the aquaculture lease area.

Five seabird species occur in the vicinity of the aquaculture leases that are listed under the Western Australian Wildlife Conservation (Specially Protected Fauna) Notice 2014, Schedule 1: Fauna that is rare or likely to become extinct. These are the:

- Lesser Noddy *Anous tenuirostris melanops*
- Hutton's Shearwater *Puffinus huttoni*
- Fairy Tern *Sternula nereis nereis*
- Indian Yellow-nosed Albatross *Thalassarche carteri,* and
- Black-browed Albatross *Thalassarche melanophris*

Both the Lesser Noddy and Fairy Tern breed at the Houtman Abrolhos, whereas the Hutton's Shearwater migrates through the region in late spring, with up to 50 birds occurring in flocks off Eastern Passage (Easter Group) and The Channel (Pelsaert Group). (Surman and Nicholson 2009a), and the two albatrosses are winter visitors (Surman *pers. obs*). Hutton's Shearwaters forage with Wedge-tailed Shearwaters on small pelagic fishes and squids, including some species likely to accumulate adjacent to sea cages.

2 Methods

2.1 Field surveys

Field surveys at the Easter and Pelsaert Groups were conducted between 18-27 June 2014 and 14-23 October 2014.

Thirty one (31) islands at the Easter Group and 35 islands across the Pelsaert Group were surveyed during each field survey. Access to potential breeding colonies on each island was possible with the use of *Persephone* - 4.5m center consul/ 50 hp aluminium research vessel.

Each island was either surveyed on foot or circumnavigated by vessel with intensive searches for nests conducted when either Silver Gull, Pacific Gull or Pied Cormorant colonies were located. Nest sites, once located were assessed for condition and/or breeding status as either;

- Old/disused – unused in recent time
- Autumn – nest considered to have been used during the previous autumn nesting season (applicable to the October survey only).
- Relined/empty – nest cup reconstructed with fresh seaweeds in preparation for breeding.
- Egg – The number of eggs (1-3) in each nest.
- Chicks – The numbers and age of chicks still in the nest, or hidden in vegetation nearby.

Estimates of breeding numbers of Silver Gulls and Pacific Gulls were undertaken using;

- Complete counts of all nests of both gull species
- Assessment of the status of each nest (i.e. active/inactive)
- Measurement of Silver Gull eggs/chicks to determine the date of commencement of breeding.

Each nest site of Silver and Pacific Gulls was plotted using a Garmin handheld GPS unit. The perimeters of colonial-nesting Pied Cormorants were plotted and then traced onto aerial photographs of each island group using GPS Visualizer and Adobe Illustrator. Nest sites were then mapped using recent aerial imagery (DoF 2012) as a base layer in ArcGIS using the Index Map Numbers shown in Figure 1.0.

2.2 Timing of nesting

Laying chronology was estimated by backdating the age of eggs, using egg water loss techniques (Wooller and Dunlop 1980, Surman and Wooller 1995). Eggs were measured and weighed at the nest, and their age in days determined with the formula below.

$$V = L.B^2$$
$$D = M/V$$

$$\text{Fresh Egg Mass} = 1.06 (V) + 0.34$$

Where M = Egg Mass, V = Volume, D = Density, L = Maximal egg length and B = maximal egg breadth.

2.3 Collection and analysis of dietary data

The hard regurgitated pellets of Silver Gulls, Pacific Gulls and Pied Cormorants were collected from areas adjacent to nest sites and known roosting areas. In the case of Pied Cormorants it was only possible to collect pellets after breeding had finished due to the high density and vulnerability to disturbance of this species.

Pellets were stored dry and sorted in the laboratory. Prey items were identified from hard parts – either exoskeletons, cephalopod beaks, seeds, shell fragments, opercula or the premaxillae or pharangeal bones of some fishes (see Bellwood 1994, Allen and Steene 1994, Edgar 1997, Lu and Ickeringill 2002, Wilson 1994).

In addition, observations of prey item remains from Pacific Gull anvil sites were also made. Pacific Gulls drop hard-shelled prey items (i.e. Gastropods and Urchins) onto rocky platforms, or on some islands exposed concrete pathways or concrete pads.

The total number of individuals of each prey type in each sample was recorded and the frequency of occurrence of each prey taxon in all samples for each seabird species.

2.4 Stable isotope analysis

2.4.1 Background

The carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) stable isotope ratios in protein based tissues can be used to provide on foraging ecology (Bond & Jones 2009), defining what is sometimes referred to as an isotopic niche.

Stable isotopes of carbon (^{13}C) and nitrogen (^{15}N) occur naturally in the environment. The ratio of the heavier isotopes to the common forms are changed by the physical sorting of biological processes such as photosynthesis in plants, or food digestion or metabolism in microbes and animals. These changes in the isotopic ratio are referred to as fractionation. The values given to the stable isotope ratios ($\delta^{13}C$ or $\delta^{15}N$) are measured in parts per thousand ($^{o}/_{oo}$) and may be positive or negative because they represent deviations from the values of standard materials (Bond & Jones 2009).

Both $\delta^{13}C$ and $\delta^{15}N$ values in consumer tissues can be used to infer the sources of carbon (energy) in food-chains if the producer signatures (the isotopic baselines) are known. Nitrogen 15 ($\delta^{15}N$) values show a stepwise increase with trophic level due to the tendency of animals to differentially excrete ^{14}N during digestion and assimilate ^{15}N during protein synthesis. The trophic position of consumer organisms can be inferred above a known producer $\delta^{15}N$ baseline (Bond & Jones 2009). The synthesis of different consumer tissues (e.g. blood, muscle and feathers) may involve different turnover rates (time periods) and variable fractionation patterns, which need to be considered when making inferences from stable-isotope data (Bond & Jones 2009).

The $\delta^{15}N$ values in marine producers such as phytoplankton will be dependent on the fractionation of the nitrogen source. This in turn reflects the various nitrifying and de-nitrifying transformations occurring through the nitrogen cycle and on nitrogen availability. Inorganic (nitrate) nitrogen is relatively enriched in ^{15}N producing a high $\delta^{15}N$ signature. Recycled (ammonia) nitrogen is less enriched and recently fixed (N_2) nitrogen is depleted in ^{15}N. The $\delta^{15}N$ signature is a combined indicator of nitrate source, availability and uptake (Graham *et al.* 2010).

Stable isotope ratios in protein-based biological materials can also be used to track anthropogenic sources of energy and nutrient in aquatic environments, e.g. measuring the scale of nitrate subsidization from treated sewage outfalls (Connolly *et al.* 2013). Artificial fish feeds supplied to sea-cage stock will have distinctive $\delta^{13}C$ or $\delta^{15}N$ values reflecting the mixture of terrestrial plant and fish-meal ingredients. The 'signature' of the feed will be translated into the tissues of consumer organisms including the farmed stock, wild fish and marine invertebrates, seabirds and marine mammals at various levels in the aquatic food-chain. Since any measurable energy and nutrient subsidy to the hosting marine environment could potentially force ecological change the method can be used to provide warning of incipient changes in consumer populations, competition or predator-prey relationships.

2.4.2 Sample collection & processing

The feathers from the three high risk ' increaser' seabird species were collected from nests or nesting areas in breeding colonies, roosts, corpses and from 'runners' (mobile gull chicks). Feathers were packaged for dry storage in labelled zip lock plastic bags. Later the selected feather samples were physically cleaned of foreign matter and washed in de-ionized water and dried.

Fresh regurgitate material was preserved in a dry state, frozen or stored in 70% ethanol for later examination and sample compilation. All samples were dried, chopped into fine pieces and ground to a flour-like consistency using a ball-mill in preparation for the laboratory analysis.

2.4.3 Stable isotope analysis

The $\delta^{13}C$ or $\delta^{15}N$ values from all the samples compiled were determined by a registered stable isotope laboratory at Monash University in Melbourne. Adequate feather samples were available from each of the three potential 'increaser' species. Seabird prey items were extracted from regurgitated pellets. The taxa for SI analysis were selected to provide a spread in trophic levels and provide for sufficient sample sizes.

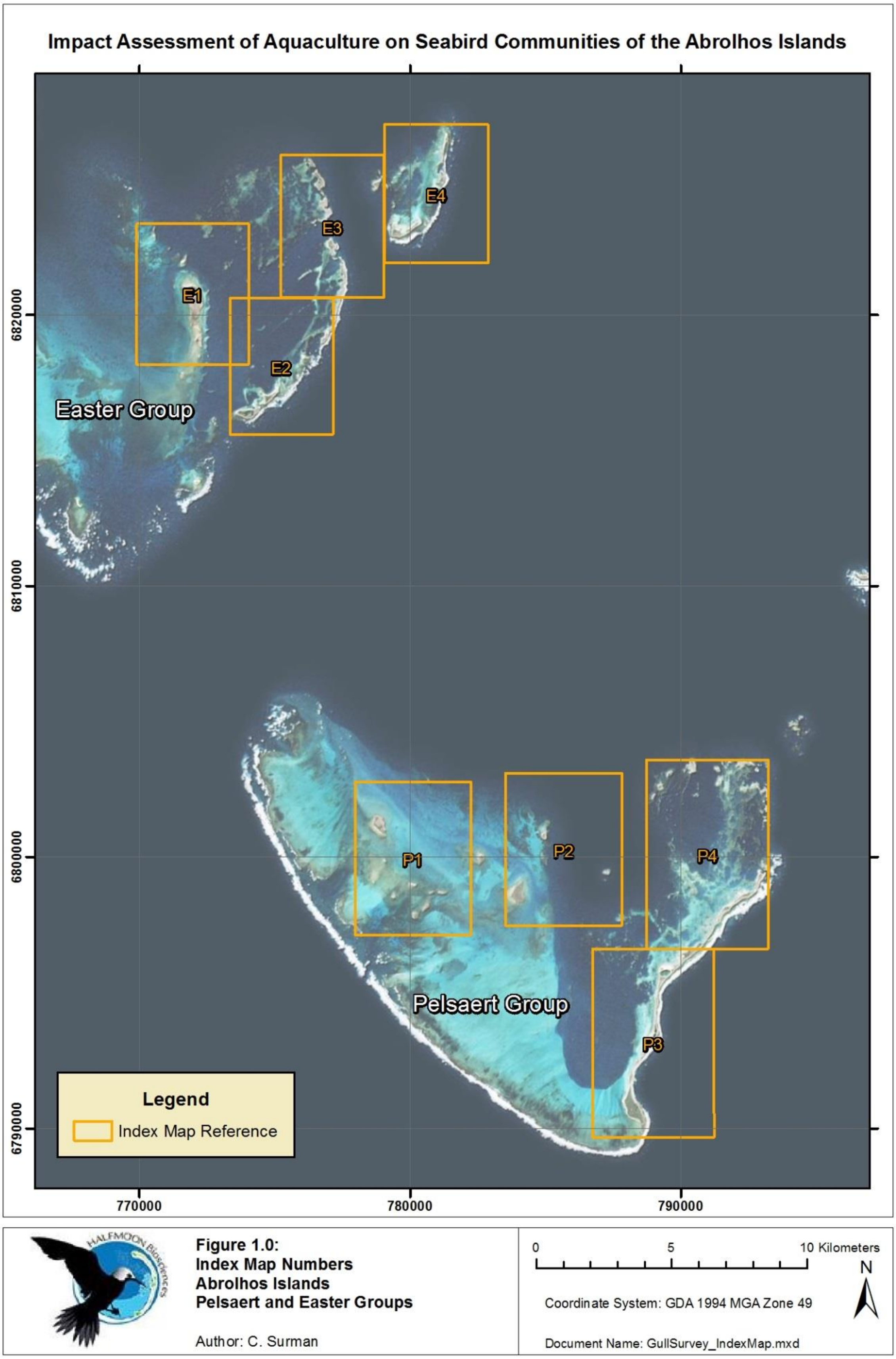


Figure 1.0:
Index Map Numbers
Abrolhos Islands
Pelsaert and Easter Groups

Author: C. Surman

3 Results

3.1 Distribution and abundance of seabirds

Figures 2.1-2.8 shows the distribution of active and inactive nest sites of Silver Gulls, Pacific Gulls and Pied Cormorants nesting in the Easter and Pelsaert Groups adjacent to the two aquaculture zones during June 2014. Figure 3.1-3.8 shows the distribution of active and inactive nest sites of Silver Gulls, Pacific Gulls and Pied Cormorants nesting in the Easter and Pelsaert Groups adjacent to the two aquaculture zones during October 2014.

3.1.1 June 2014

A total of 85 Silver Gull nests and 22 Pacific Gull nests were located across the two groups during the June 2014 survey (Table 3.1 and 3.2). Most Silver Gull nests were located in the Pelsaert Group during June, with most on Newman Island (24) and Post Office Island (18). However, of the 85 Silver Gull nests located, only one contained eggs, and four contain chicks at a time when autumn-nesting would usually be in full swing. As Pacific Gulls area summer breeding species, it was not surprising to locate only old or nests recently used from the previous summer.

Table 3.1: Nest contents of Silver Gull nests located during surveys of the Easter and Pelsaert Groups, June 2014.

Island			**Nest Contents**					
Pelsaert Group	**Old Nest**	**Empty**	**1 Egg**	**2 Egg**	**3 Egg**	**Chick**	**Runner**	**Total**
Coronation	2	0	0	0	0	2	0	4
Eight	0	1	0	0	0	0	0	1
Gun	1	0	0	0	0	0	0	1
Newman	7	15	0	1	0	1	0	24
One	4	0	0	0	0	0	0	4
Post Office	8	9	0	0	0	1	0	18
Stick	1	0	0	0	0	0	0	1
Sweet	1	3	0	0	0	0	0	4
Pelsaert Group Total	**24**	**28**	**0**	**1**	**0**	**4**	**0**	**57**
Easter Group								
Rat	7	6	0	0	0	0	0	13
Wooded	6	9	0	0	0	0	0	15
Easter Group Total	**13**	**15**	**0**	**0**	**0**	**0**	**0**	**28**
TOTAL	**37**	**43**	**0**	**1**	**0**	**4**	**0**	**85**

Table 3.2: Nest contents of Pacific Gull nests located during surveys of the Easter and Pelsaert Groups, June 2014.

Island	Nest Contents							
Pelsaert Group	Old Nest	Empty	1 Egg	2 Egg	3 Egg	Chick	Runner	Total
Eight	0	2	0	0	0	0	0	2
Pelsaert	2	7	0	0	0	0	0	9
Stick	0	1	0	0	0	0	0	1
Three	3	1	0	0	0	0	0	4
Pelsaert Group Total	**5**	**11**	**0**	**0**	**0**	**0**	**0**	**16**
Easter Group								
Leos	0	3	0	0	0	0	0	3
Morley	1	1	0	0	0	0	0	2
Sandy	1	0	0	0	0	0	0	1
Easter Group Total	**2**	**4**	**0**	**0**	**0**	**0**	**0**	**6**
TOTAL	**7**	**15**	**0**	**0**	**0**	**0**	**0**	**22**

3.1.2 October 2014

A total of 237 Silver Gull nests and 87 Pacific Gull nests were located across the two groups during the October 2014 survey (Table 3.3 and 3.4). Of these 144 Silver Gull nests were located in the Pelsaert Group and 93 in the Easter Group. The largest Silver Gull colonies in the Pelsaert Group were on Pelsaert Island (60 nests), Post Office Island (38 nests) and Newman Island (28 nests). In the Easter Group nearly half of all nests were located on Wooded Island (45 nests). Of the 237 nests, only 50 (21.9%) were occupied (26 contained eggs and 24 chicks). In contrast 77 (32.6%) were old nests, and 110 (46.4%) remained empty.

Pacific Gulls tend to nest solitarily, although a single colony of eight pairs of Pacific Gulls nests on Pelsaert Island. Of the 51 Pacific Gull nests located in the Pelsaert Group, 18 (35.3%) were on Pelsaert Island, and seven (13.7%) on Three Island. Within the Easter Group, eight nests (22.2%) were located on Leo's Island, with five nests on each of Rat Island, Suomi Island and Wooded Island. Across the two groups, 14 Pacific Gull nests contained eggs and 26 contained chicks. This agrees with nesting commencing in late August for this species (Surman 1998).

A census of Pied Cormorant nests located breeding colonies on three islands in each group, although only the Wooded Island colony appeared to have been active during the 2014 breeding season (Table 3.5). A census of occupied nests at the Wooded Island colony taken from an aerial photograph obtained in October 2014 showed that 676 of the 1222 nests (55.3%) were active.

Table 3.3: Nest contents of Silver Gull nests located during surveys of the Easter and Pelsaert Groups, October 2014.

Island	Nest Contents							
Pelsaert Group	**Old Nest**	**Empty**	**1 Egg**	**2 Egg**	**3 Egg**	**Chick**	**Runner**	**Total**
Burnett Islet	0	0	0	0	0	1	0	1
Burton	0	1	0	0	0	0	0	1
Coronation	1	2	0	0	0	2	0	5
Lagoon	0	3	0	0	0	0	0	3
Newman	13	11	1	0	0	3	0	28
One	1	1	0	0	0	0	0	2
Pelsaert	21	23	3	8	0	5	0	60
Post Office	15	17	3	0	0	3	0	38
Robinson	0	1	0	0	0	0	0	1
Rotundella	0	1	0	0	0	0	0	1
Stick	0	2	0	0	0	0	0	2
Sweet	0	1	0	0	0	1	0	2
Pelsaert Group Total	**51**	**63**	**7**	**8**	**0**	**15**	**0**	**144**
Easter Group								
Bynoe	4	4	0	2	0	0	0	10
Keru	3	2	0	0	0	1	0	6
Leos	3	12	1	0	0	0	0	16
Rat	6	5	0	0	0	3	0	14
Stokes	1	0	0	0	0	0	0	1
Suomi	0	1	0	0	0	0	0	1
Wooded	9	23	6	2	0	5	0	45
Easter Group Total	**26**	**47**	**7**	**4**	**0**	**9**	**0**	**93**
TOTAL	**77**	**110**	**14**	**12**	**0**	**24**	**0**	**237**

Table 3.4: Nest contents of Pacific Gull nests located during surveys of the Easter and Pelsaert Groups, October 2014.

Island	**Nest Contents**							
Pelsaert Group	**Old Nest**	**Empty**	**1 Egg**	**2 Egg**	**3 Egg**	**Chick**	**Runner**	**Total**
Arthur	0	1	0	0	0	0	0	1
Basile	0	0	0	0	0	1	0	1
Burnett Islet	0	0	0	0	0	1	0	1
Burton	0	0	1	0	0	0	0	1
Eight	1	1	0	1	0	0	0	3
Gun	2	1	1	0	0	1	0	5
Jackson's	0	0	0	0	0	1	0	1
Jon Jim	0	0	0	0	0	1	0	1
Lagoon	0	1	0	0	0	0	0	1
Little Jackson	0	0	0	0	0	1	0	1
One	0	1	0	0	0	1	0	2
Pelsaert	4	7	1	3	0	3	0	18
Post Office	0	0	0	0	0	1	0	1
Robinson	1	0	0	0	0	0	0	1
Square	1	0	1	0	0	0	0	2
Stick	0	0	0	1	0	0	0	1
Sweet	0	1	1	0	0	0	0	2
Three	1	5	0	0	0	1	0	7
Travia mid	0	0	0	0	0	1	0	1
Pelsaert Group Total	**10**	**18**	**5**	**5**	**0**	**13**	**0**	**51**
Easter Group								
Alexander	0	0	0	0	0	2	0	2
Bynoe	0	0	1	0	0	0	0	1
Campbell	0	4	0	0	0	0	0	4
Gibson	0	1	0	0	0	0	0	1
Joe Smith	0	0	0	0	0	1	0	1
Keru	0	0	0	0	0	1	0	1
Leos	0	4	2	0	0	2	0	8
Morley	0	1	0	0	0	0	0	1
Morley Islet	0	0	0	1	0	0	0	1
Rat	1	1	0	0	0	3	0	5
Shearwater Islet	0	0	0	0	0	1	0	1
Suomi	0	3	0	0	0	2	0	5
Wooded	2	2	0	0	0	1	0	5
Easter Group Total	**3**	**16**	**3**	**1**	**0**	**13**	**0**	**36**
TOTAL	**13**	**34**	**8**	**6**	**0**	**26**	**0**	**87**

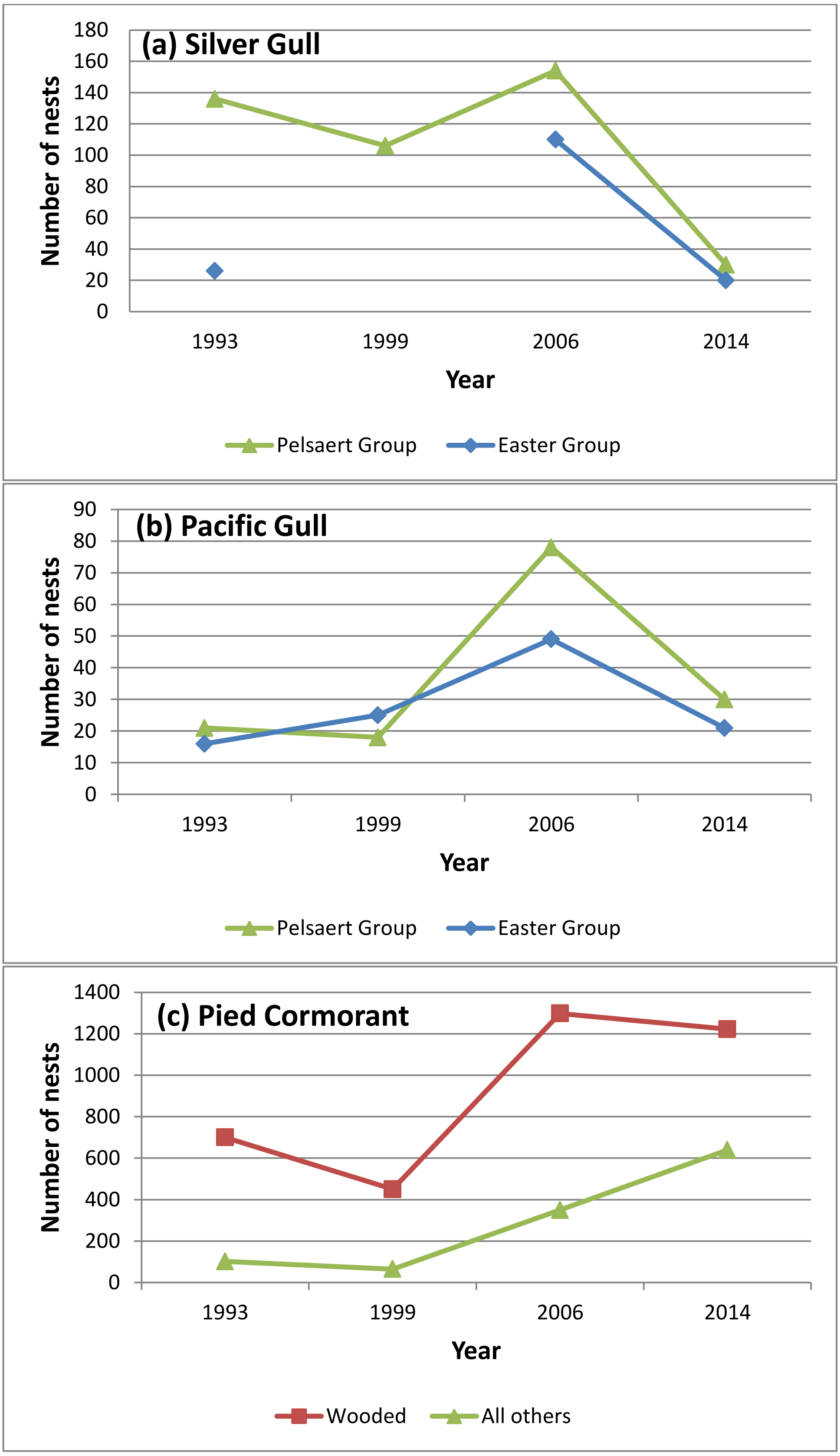
Table 3.5: Nest contents of Pied Cormorant nests located during surveys of the Easter and Pelsaert Groups, October 2014.

Island	Nest Contents				
Pelsaert Group	**Old Nest**	**Empty**	**1 Egg**	**Chick**	**Total**
Eight	0	89	0		89
Gun	90	0	0		
Three	0	176	0		
Pelsaert Group Total	**90**	**265**	**0**	**0**	**89**
Easter Group					
Roma Islet N		198			
Roma Islet S		86			
Wooded		546	607	69	1222
Easter Group Total	**0**	**830**	**607**	**69**	**1222**
TOTAL	**90**	**1095**	**607**	**69**	**1311**

3.2 Historical seabird numbers

There has been a decline in the numbers of active Silver Gull and Pacific Gull nests at the Houtman Abrolhos since 2006 (Figure 3.2). Presumably, since the change in the timing of the fishing season of the rock-lobster fishery, there has been a reduced availability in food for gulls. Unlike the gulls however, Pied Cormorants continue to remain at relatively stable numbers, most likely due to little change in their usual food supply, and as they are not known to exploit discarded rock-lobster fishing bait.

Figure 3.2: The absolute numbers of active Silver Gull, Pied Cormorant and Pacific Gull nests recorded during annual survey counts between 1993 and 2014 (Fuller *et al.* 1994, Burbidge and Fuller 2004, Surman and Nicholson 2009a).



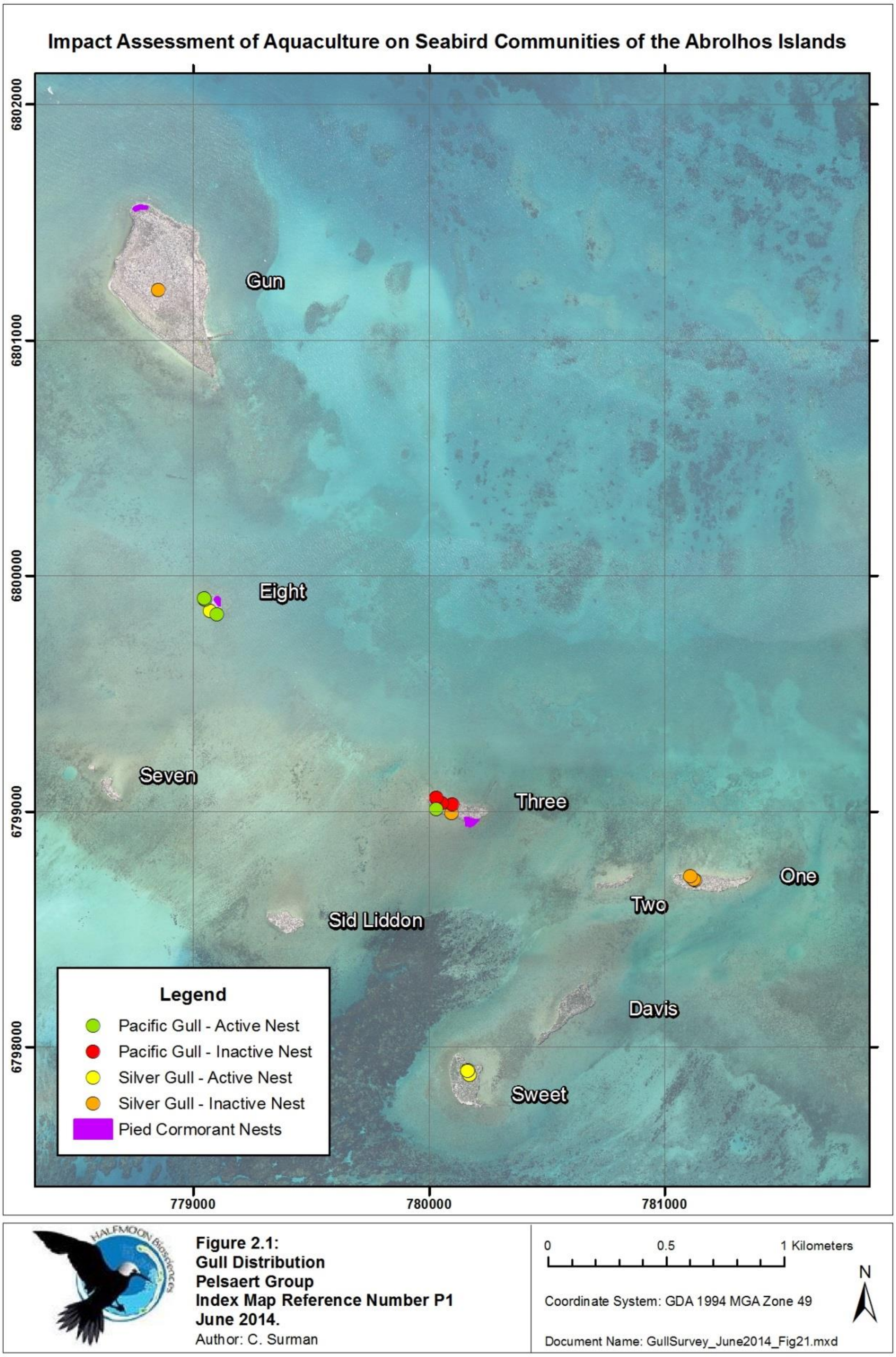


Figure 2.1:
Gull Distribution
Pelsaert Group
Index Map Reference Number P1
June 2014.
Author: C. Surman

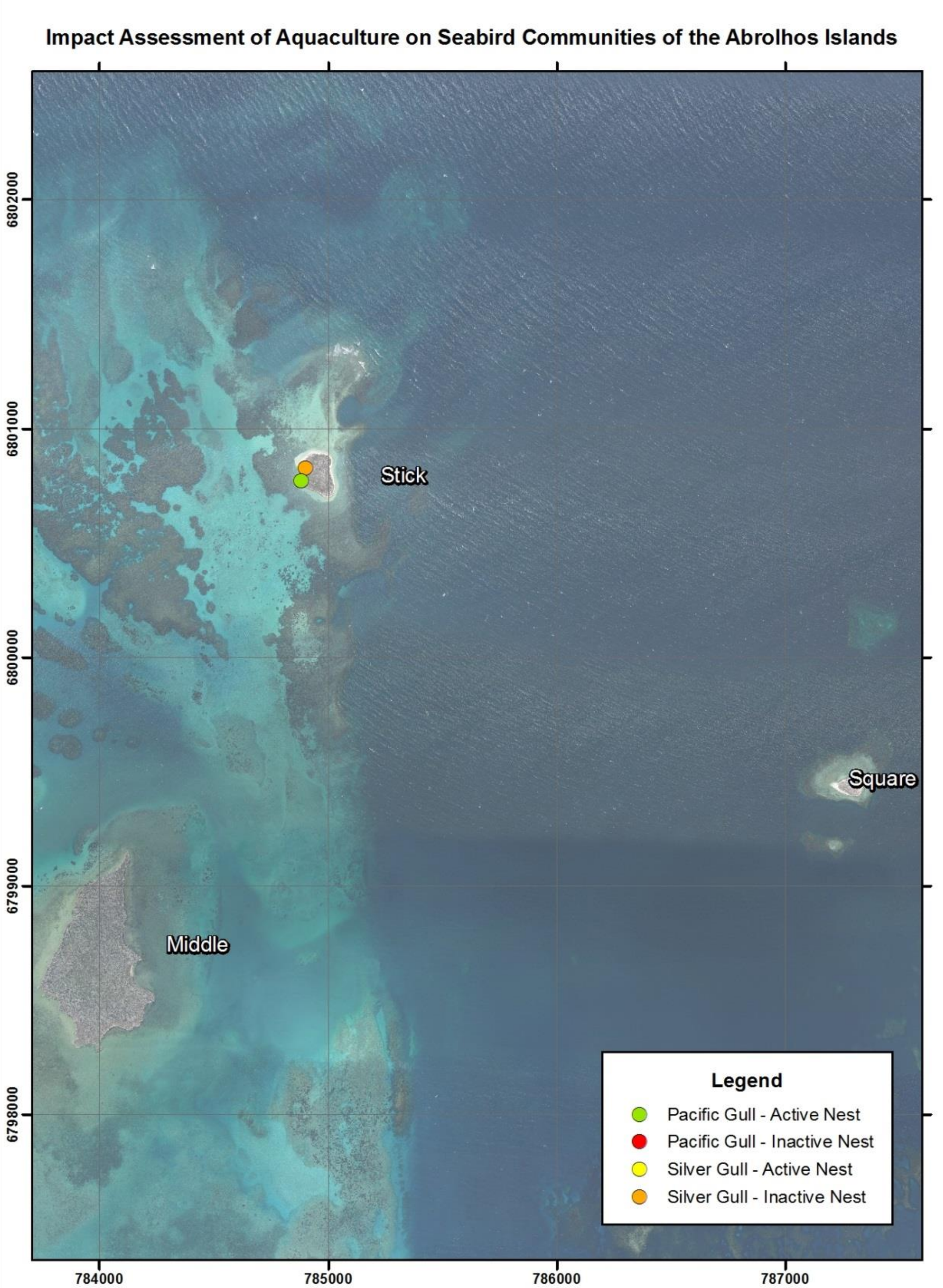


Figure 2.2:
Gull Distribution
Pelsaert Group
Index Map Reference Number P2
June 2014.
Author: C. Surman

0 0.5 1 Kilometers

N

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_June2014_Fig22.mxd

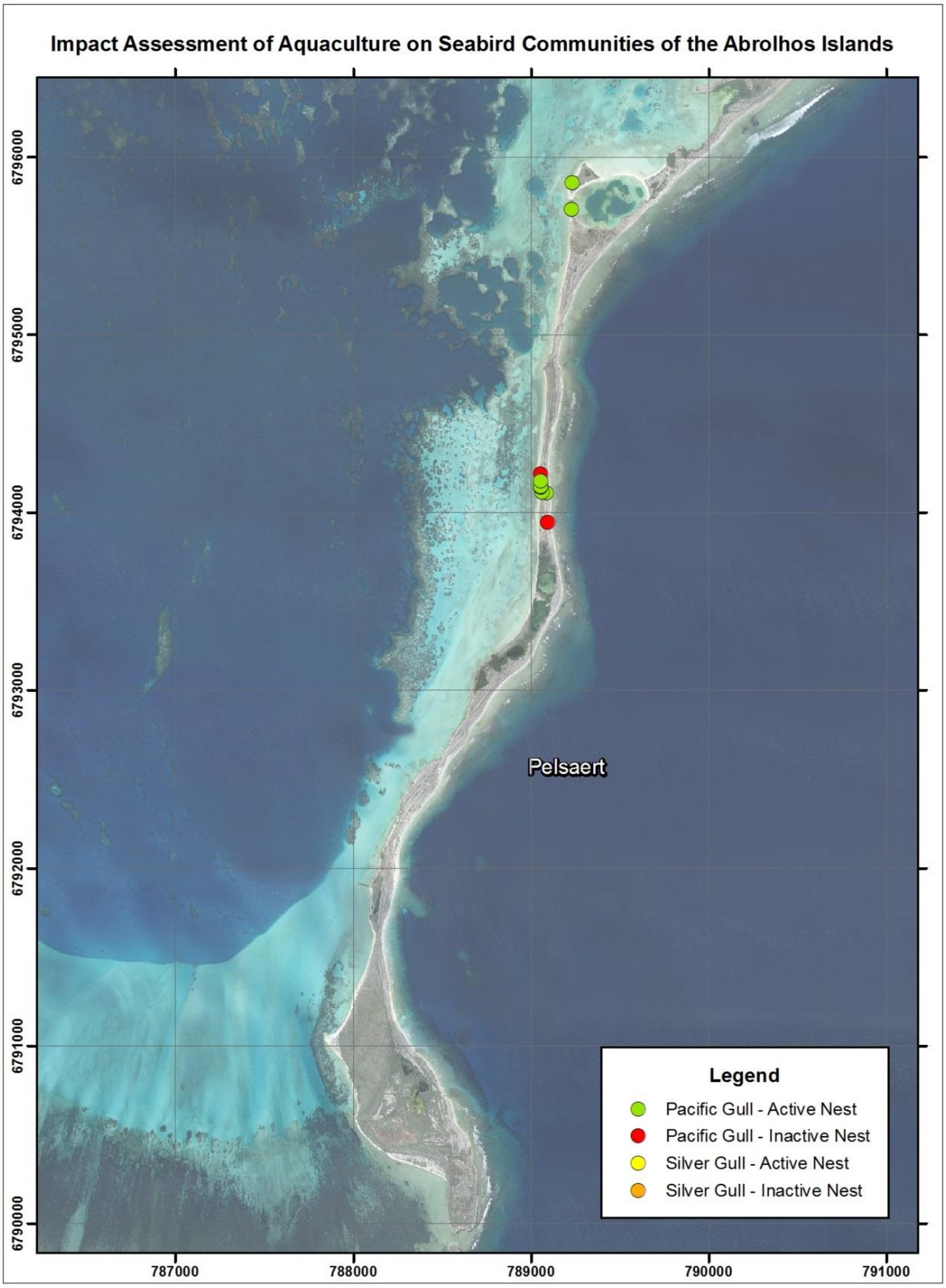


Figure 2.3:
Gull Distribution
Pelsaert Group
Index Map Reference Number P3
June 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

N

Document Name: GullSurvey_June2014_Fig23.mxd

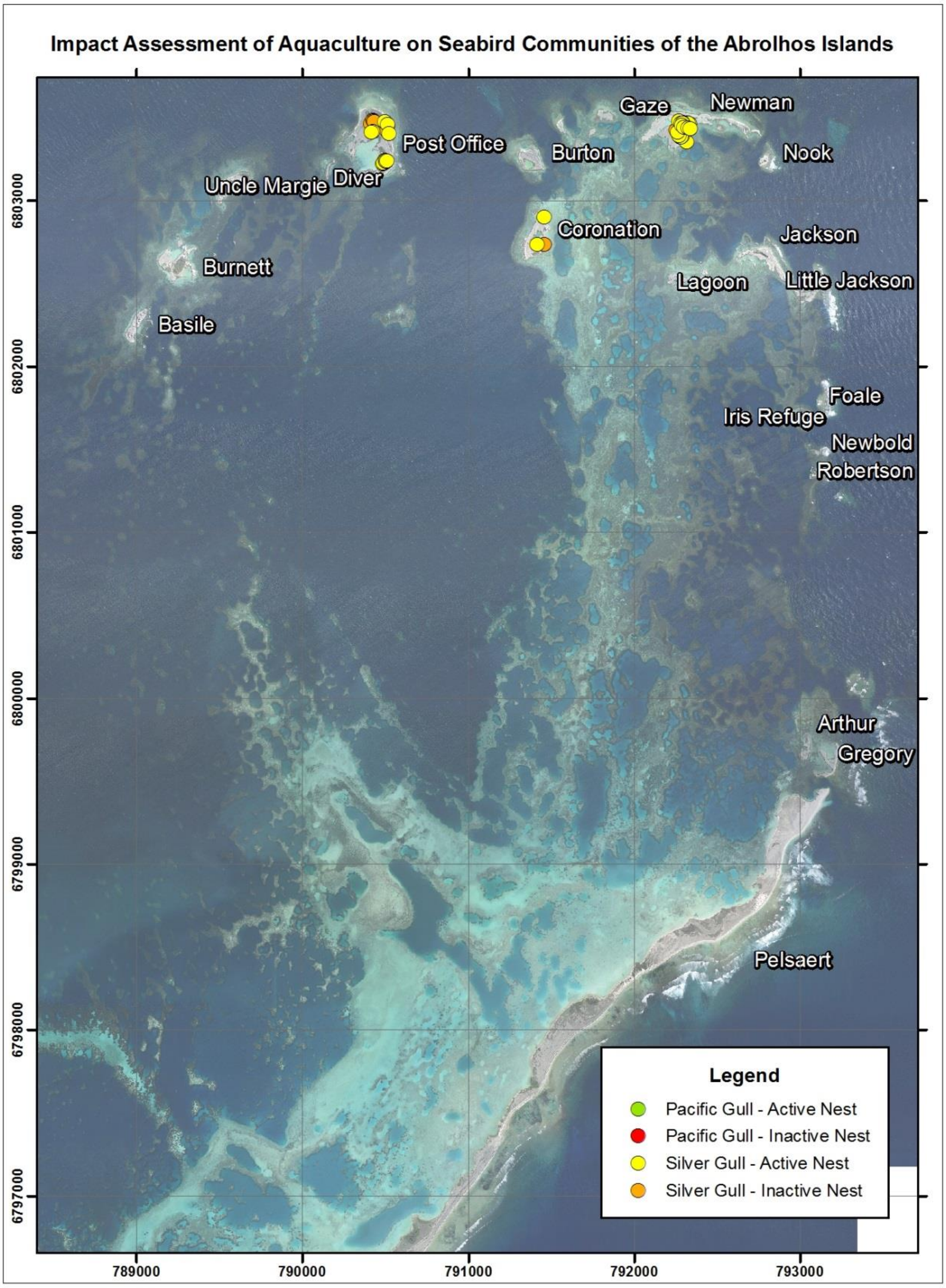


Figure 2.4:
Gull Distribution
Pelsaert Group
Index Map Reference Number P4
June 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

N

Document Name: GullSurvey_June2014_Fig24.mxd

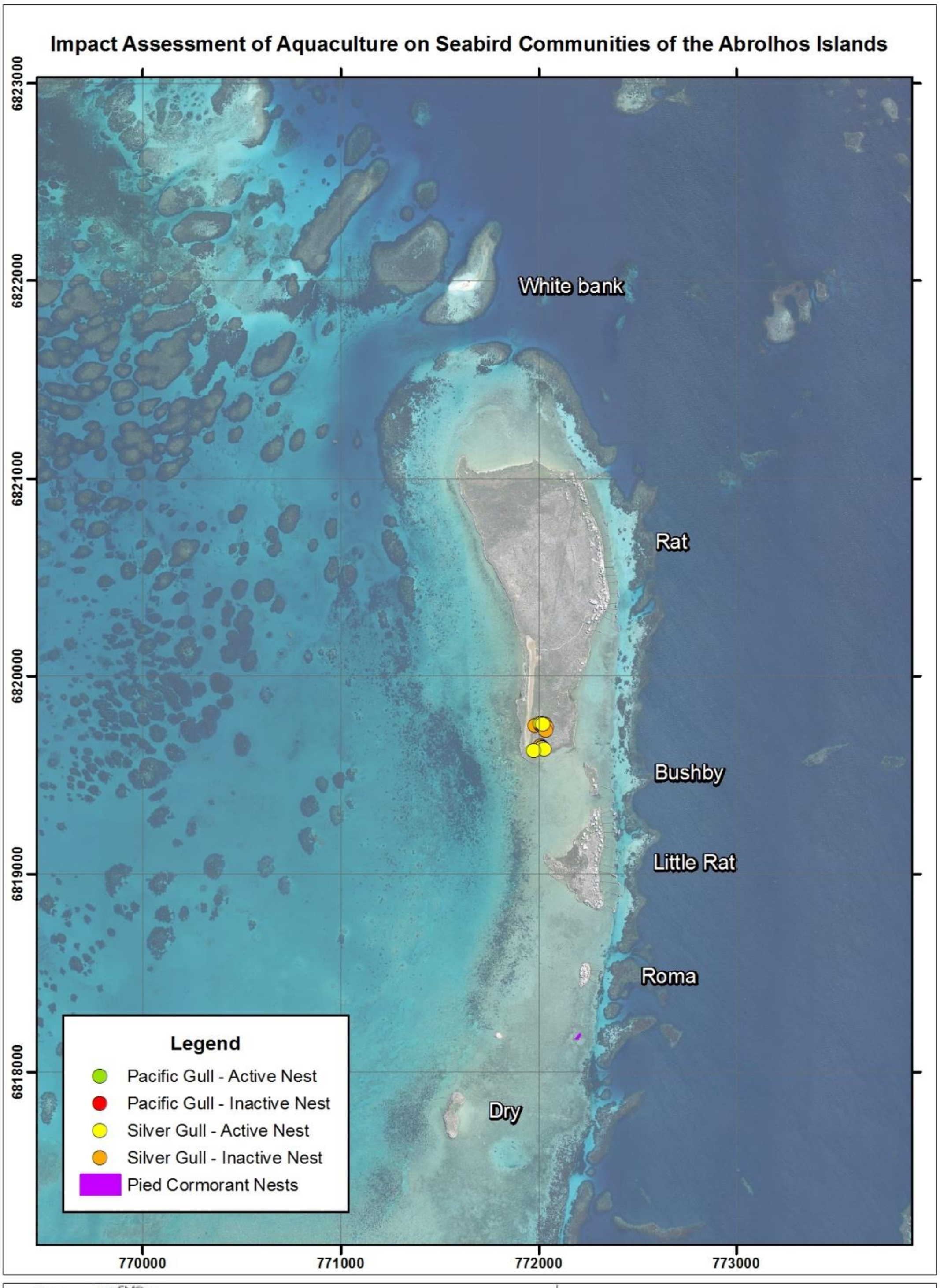


Figure 2.5:
Gull Distribution
Easter Group
Index Map Reference Number E1
June 2014.
Author: C. Surman

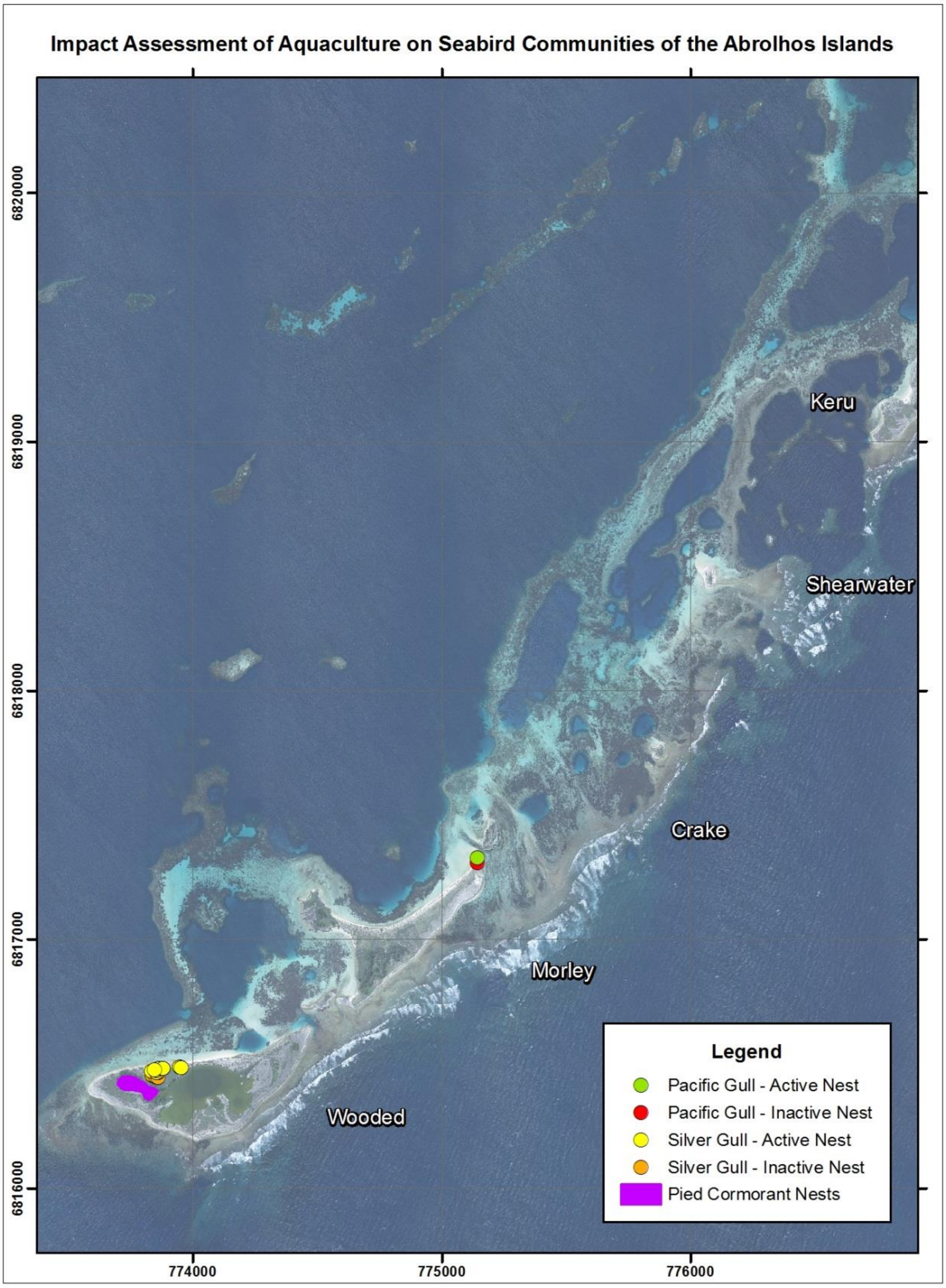


Figure 2.6:
Gull Distribution
Easter Group
Index Map Reference Number E2
June 2014.
Author: C. Surman

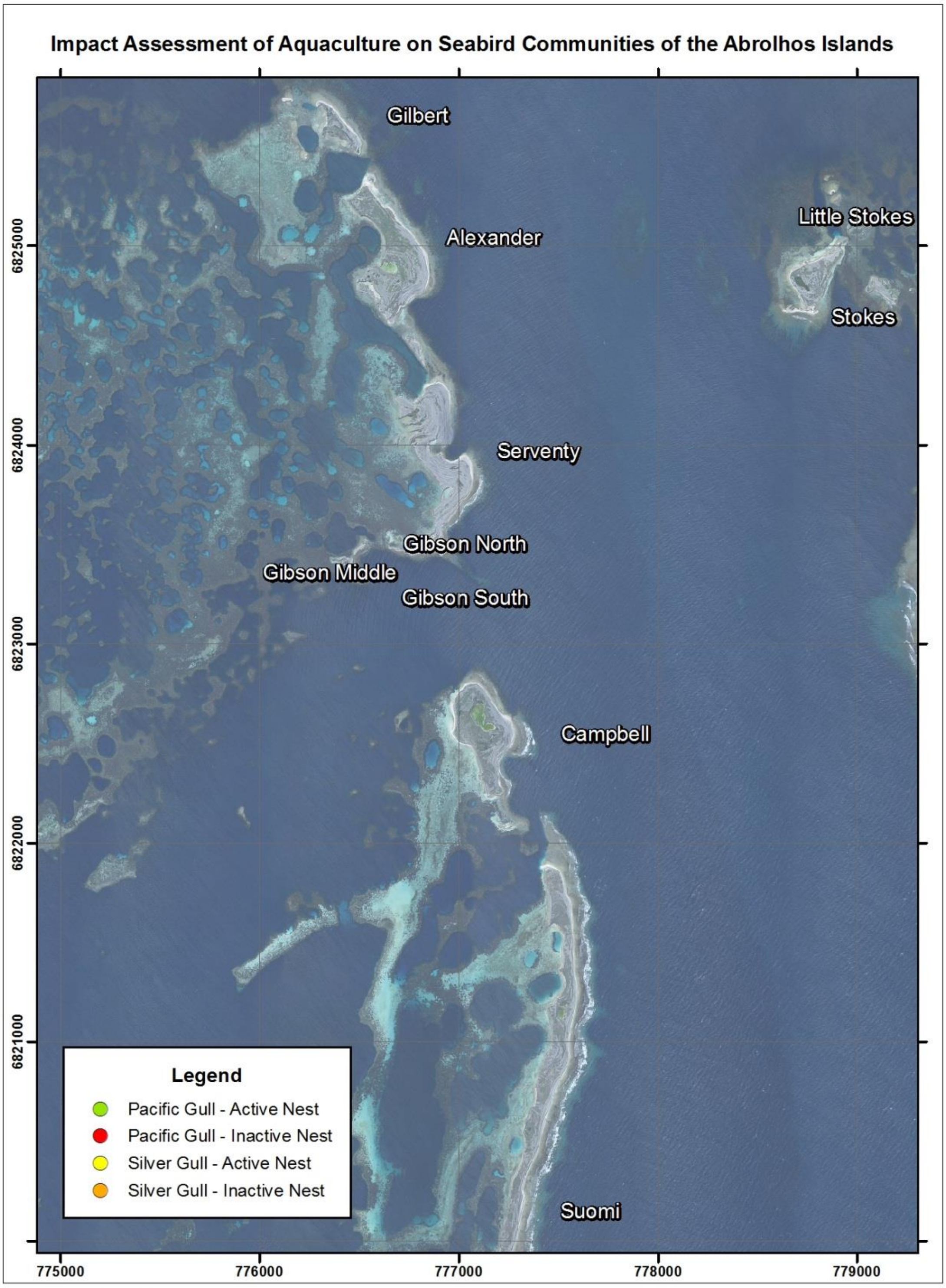


Figure 2.7:
Gull Distribution
Pelsaert Group
Index Map Reference Number E3
June 2014.
Author: C. Surman

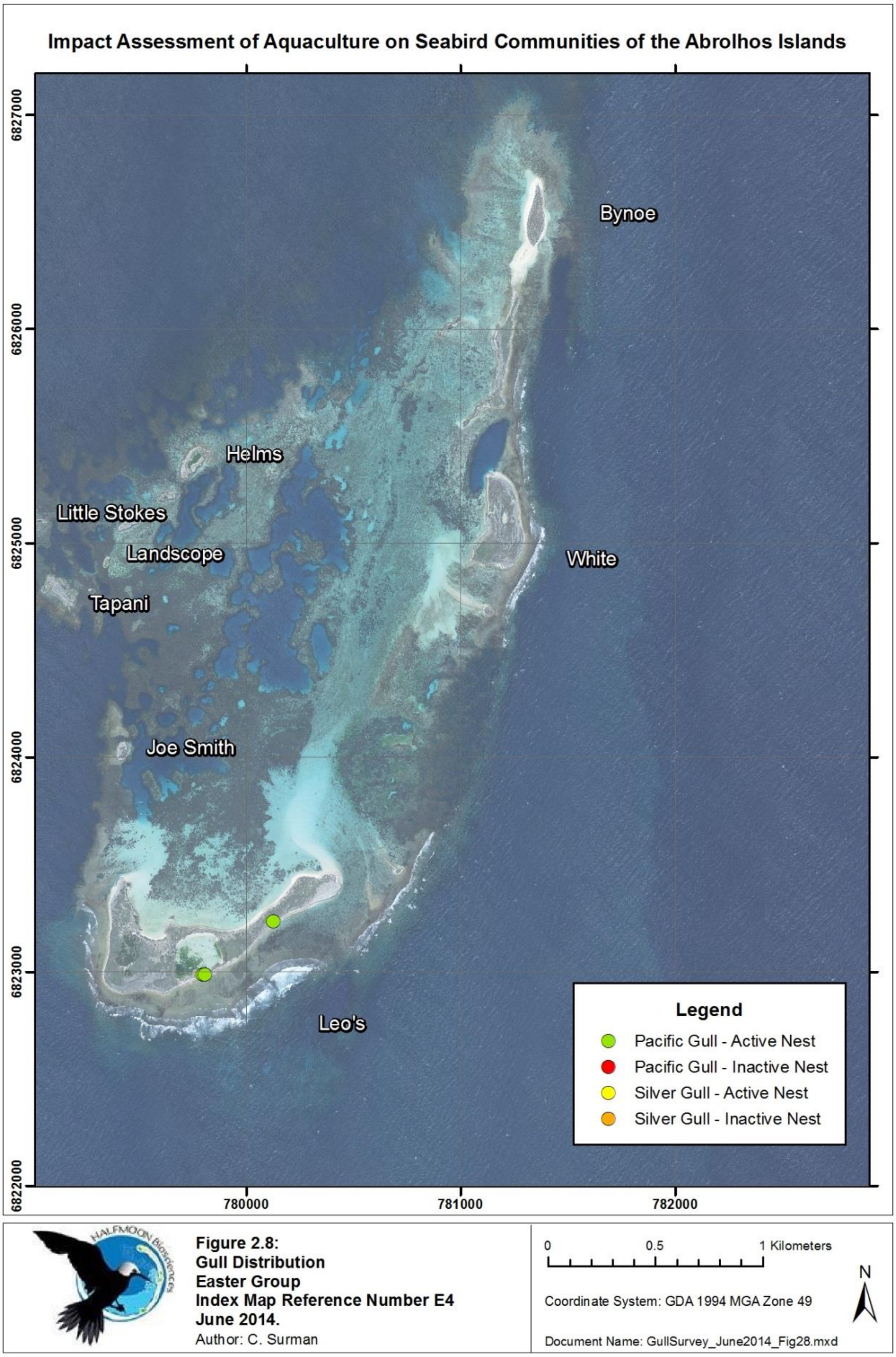


Figure 2.8:
Gull Distribution
Easter Group
Index Map Reference Number E4
June 2014.
Author: C. Surman

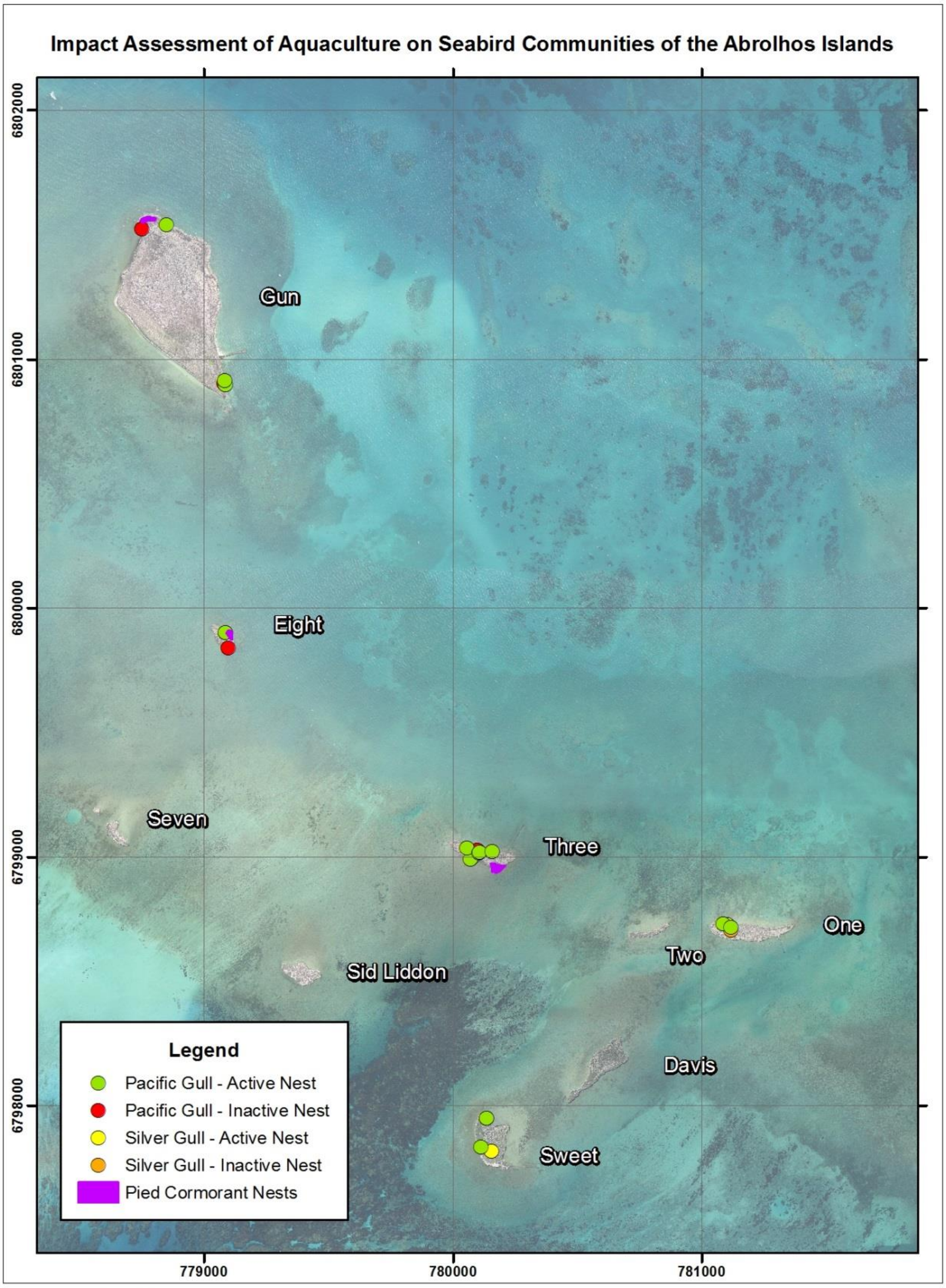


Figure 3.1:
Gull Distribution
Pelsaert Group
Index Map Reference Number P1
October 2014.
Author: C. Surman

0 0.5 1 Kilometers

N

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_October2014_Fig31.mxd

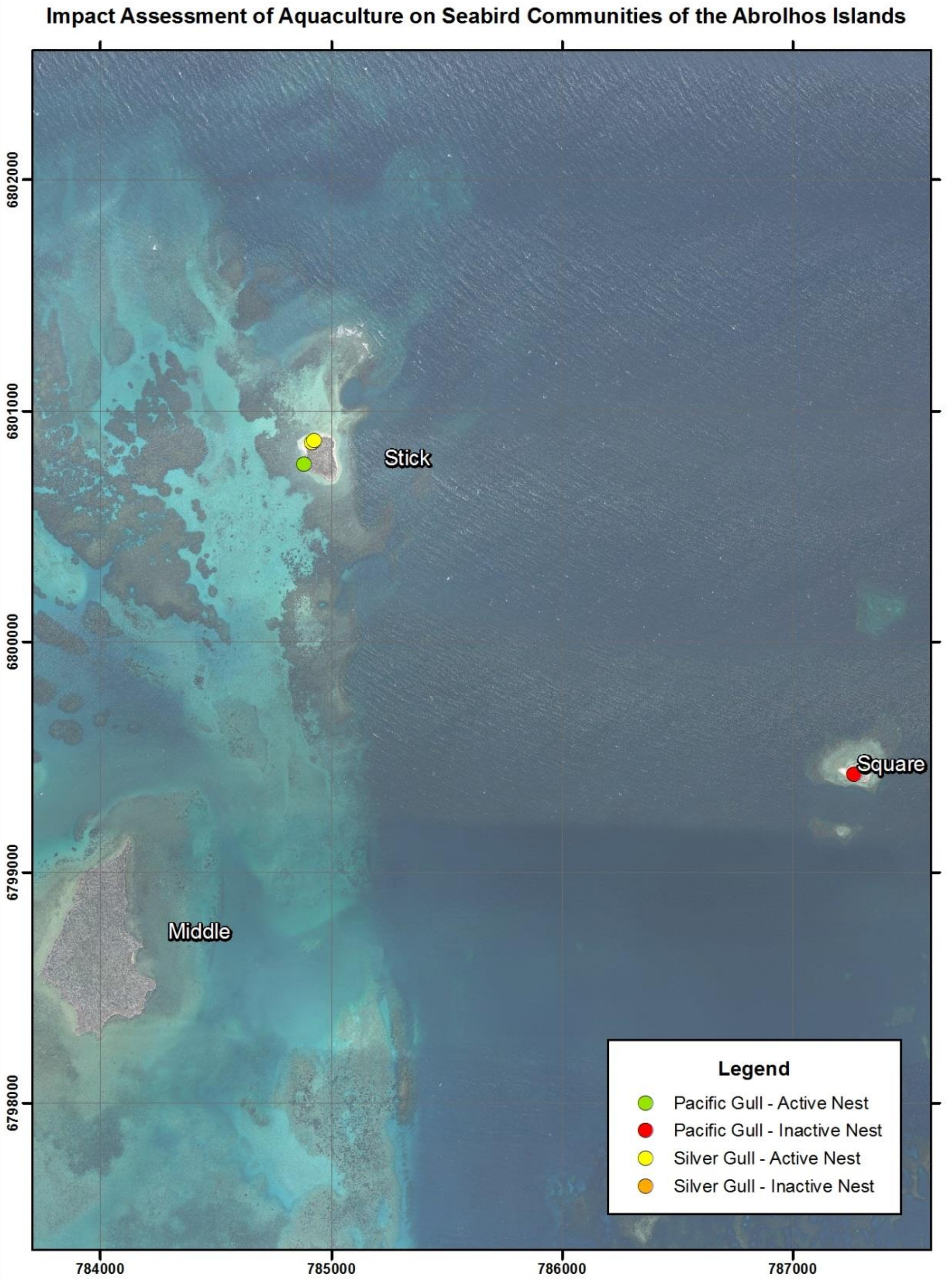


Figure 3.2:
Gull Distribution
Pelsaert Group
Index Map Reference Number P2
October 2014.
Author: C. Surman

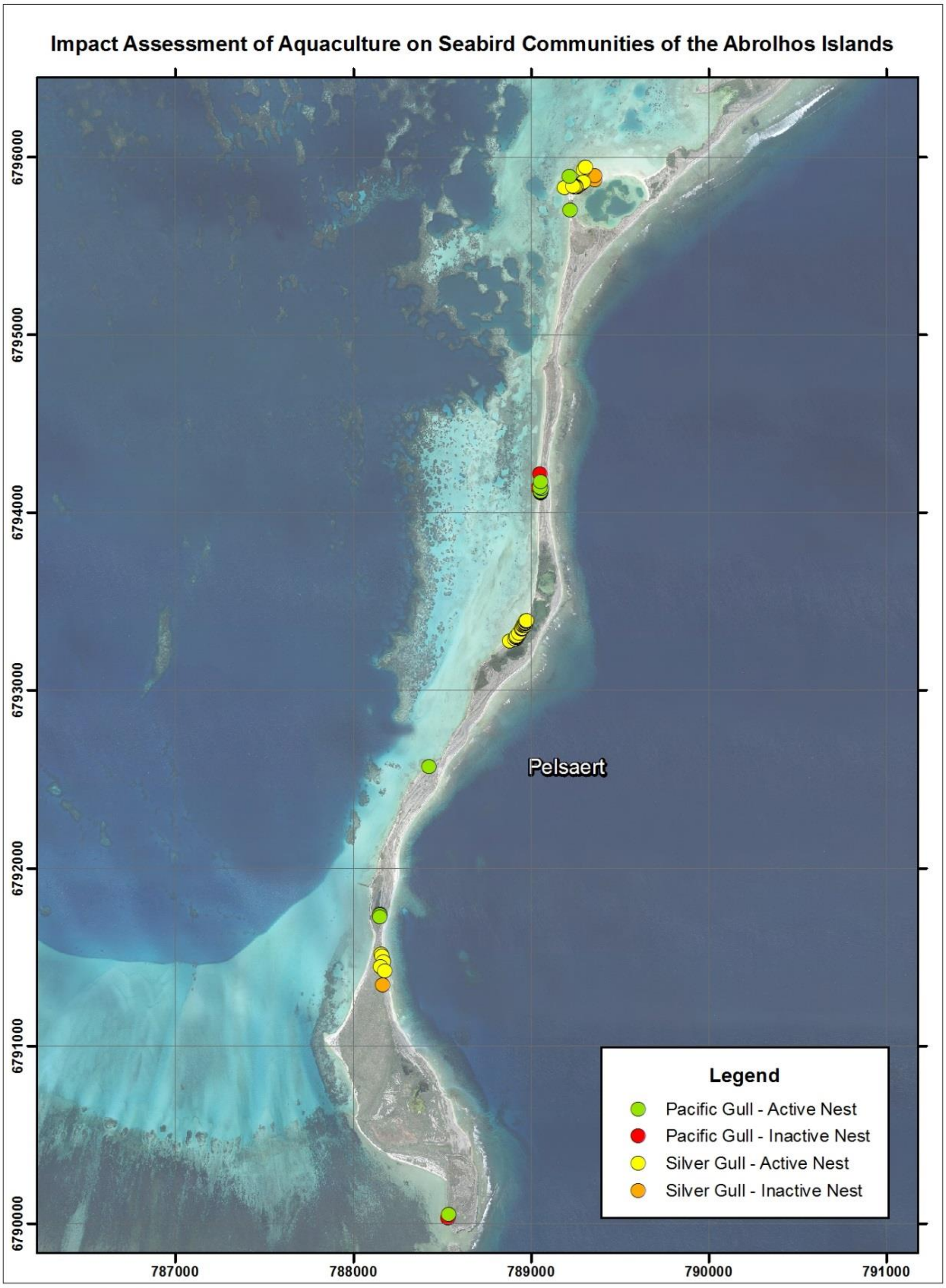


Figure 3.3:
Gull Distribution
Pelsaert Group
Index Map Reference Number P3
October 2014.
Author: C. Surman

0 0.5 1 Kilometers
Coordinate System: GDA 1994 MGA Zone 49
N
Document Name: GullSurvey_October2014_Fig33.mxd

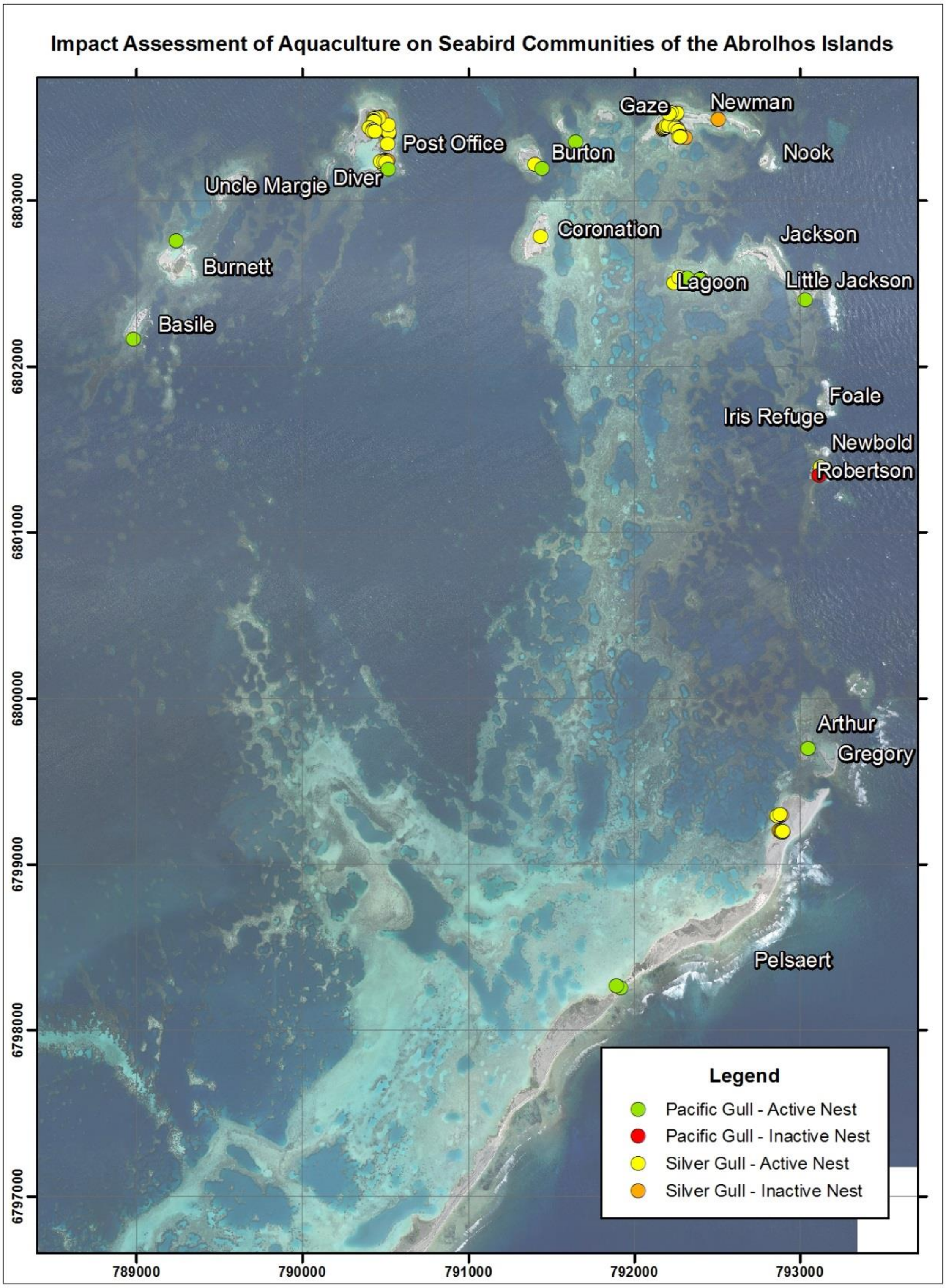


Figure 3.4:
Gull Distribution
Pelsaert Group
Index Map Reference Number P4
October 2014.
Author: C. Surman

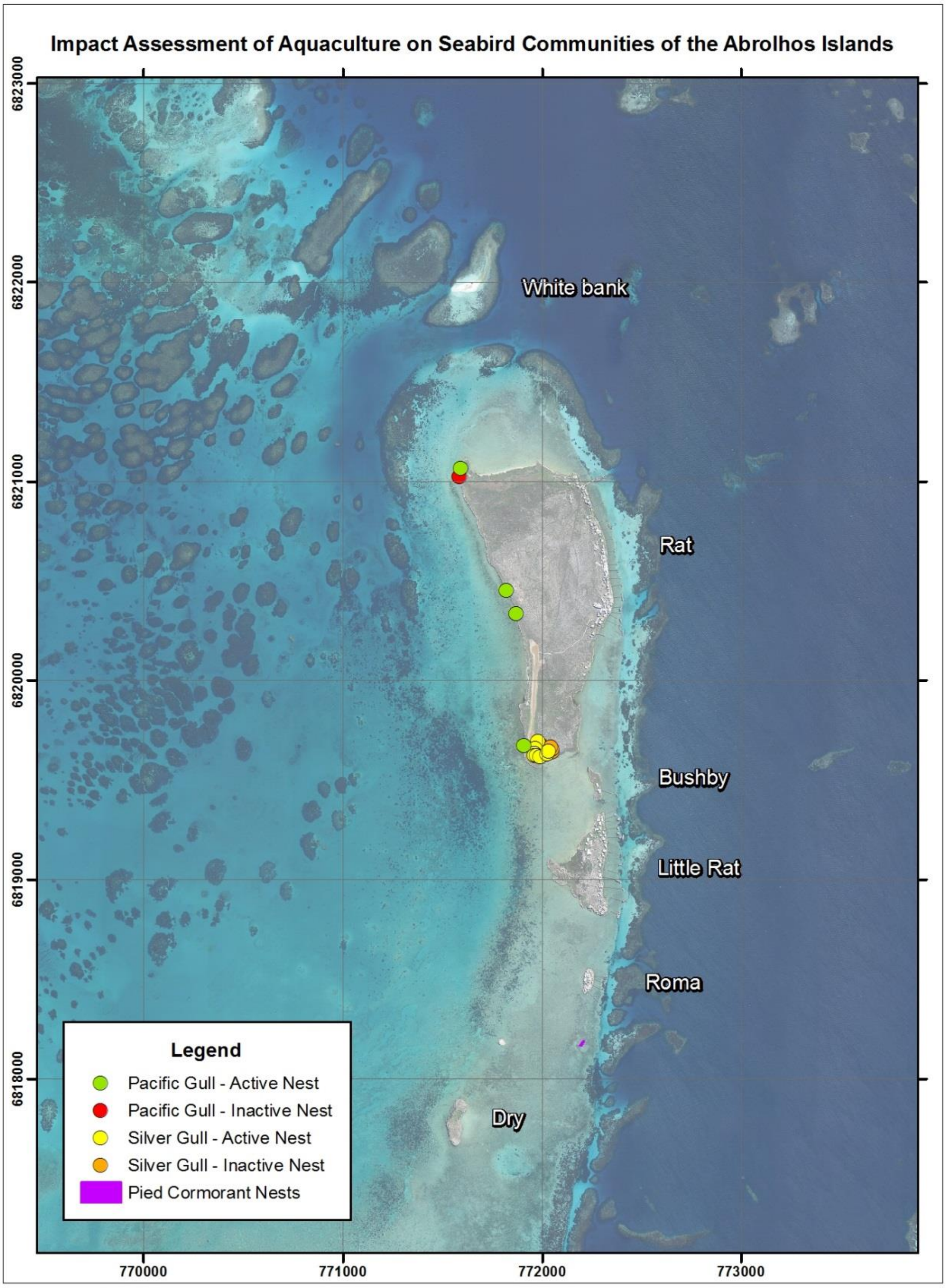


Figure 3.5:
Gull Distribution
Easter Group
Index Map Reference Number E1
October 2014.
Author: C. Surman

0 0.5 1 Kilometers
N
Coordinate System: GDA 1994 MGA Zone 49
Document Name: GullSurvey_October2014_Fig35.mxd

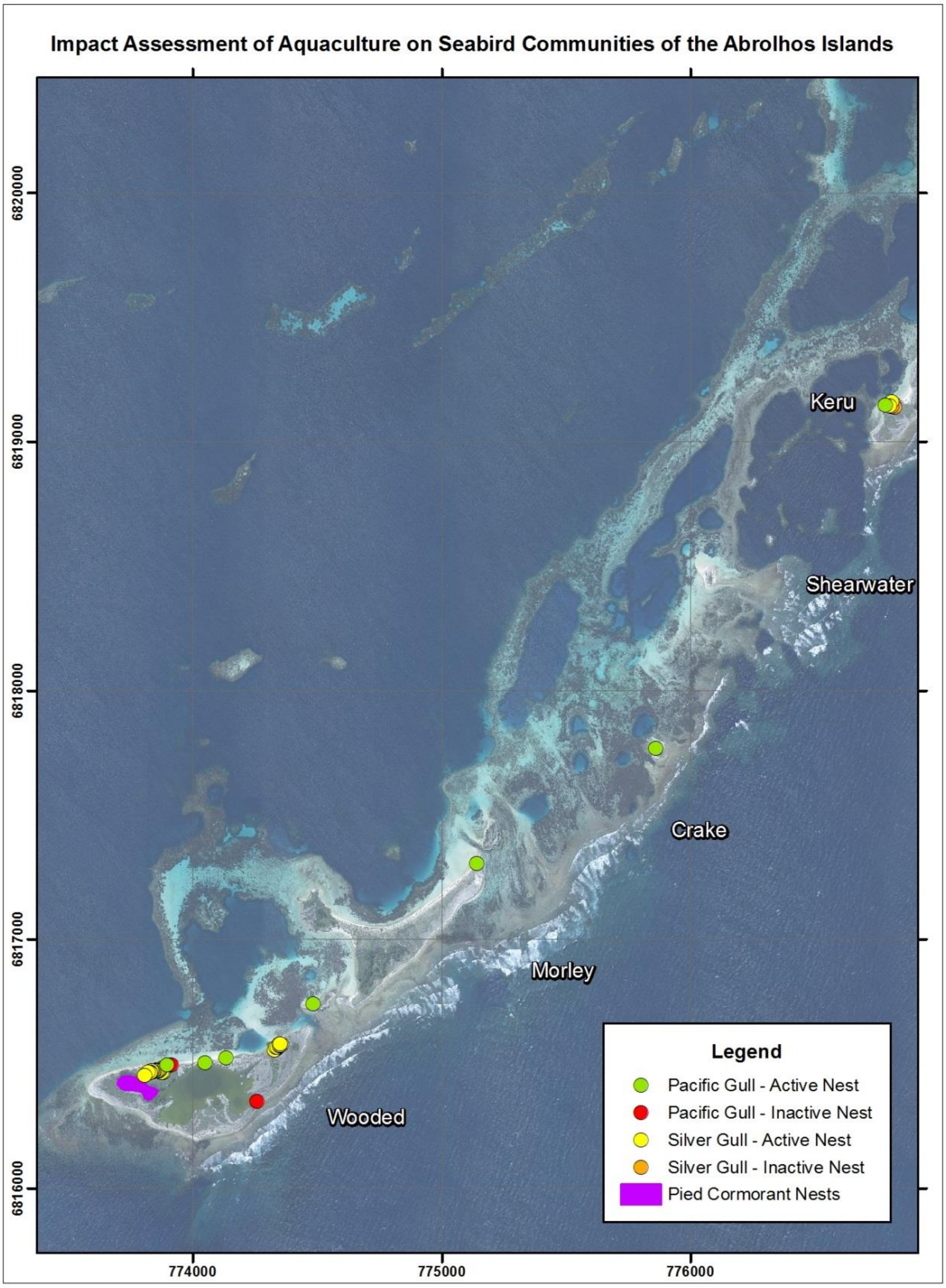


Figure 3.6:
Gull Distribution
Easter Group
Index Map Reference Number E2
October 2014.
Author: C. Surman

0 0.5 1 Kilometers

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_October2014_Fig36.mxd

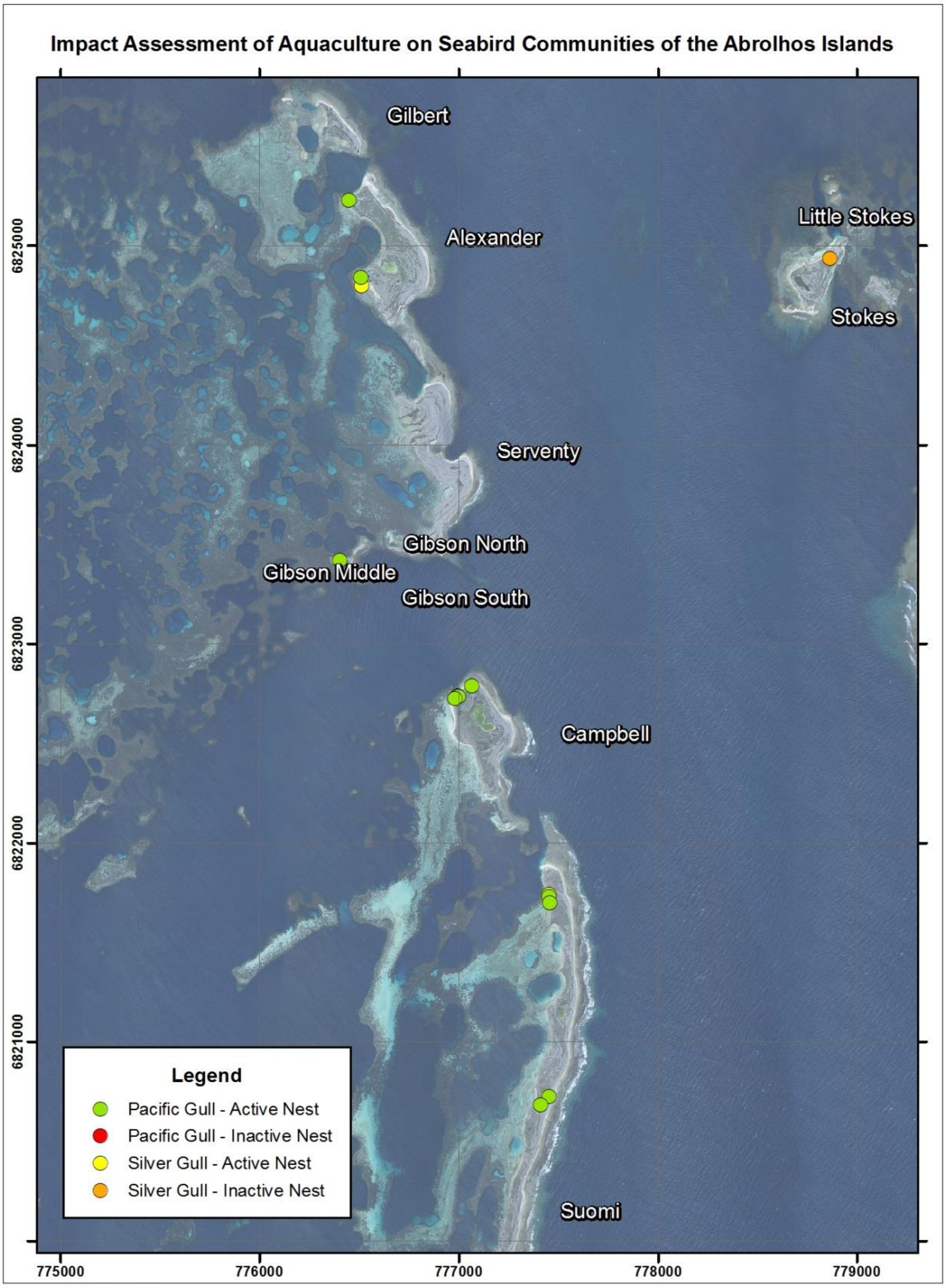


Figure 3.7:
Gull Distribution
Easter Group
Index Map Reference Number E3
October 2014.
Author: C. Surman

Coordinate System: GDA 1994 MGA Zone 49

Document Name: GullSurvey_October2014_Fig37.mxd

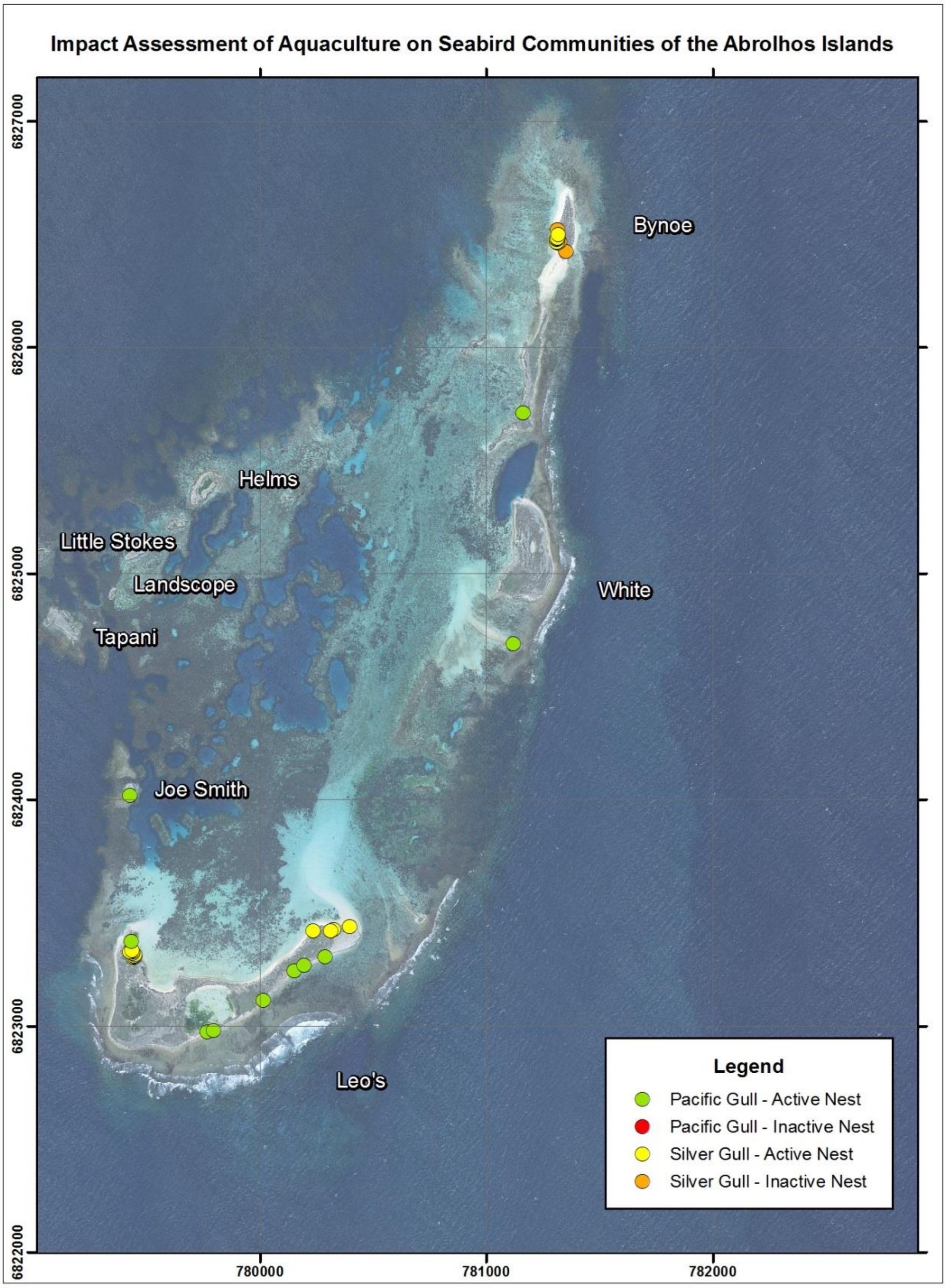


Figure 3.8:
Gull Distribution
Easter Group
Index Map Reference Number E4
October 2014.
Author: C. Surman

0 0.5 1 Kilometers
Coordinate System: GDA 1994 MGA Zone 49
N
Document Name: GullSurvey_October2014_Fig38.mxd

3.3 Diet

Table 3.6 and Figure 3.3 summarises the dietary data from regurgitated pellets from Silver Gulls, Pacific Gulls and Pied Cormorants collected during the 2014 field season. A total of 40 Pied Cormorant, 78 Silver Gull and 93 Pacific Gulls regurgitates were collected and sorted. Overall, 45 species of prey ranging from bird remains to insects were identified from regurgitated pellets.

The regurgitated pellets of Pied Cormorants were dominated by the remains of fishes, specifically Parrotfishes (Scaridae) and Wrasses (Labridae), which occurred in 50% and 10% of samples. Due to the degraded nature of pellets, there was a relatively high proportion of unidentified bony fish material, much of which contained fragmented portions of pharyngeal bones that could not be assigned to either the Scaridae or Labridae.

The two gull species had a wide-ranging diet. Overall the Silver Gull took 25 species of prey comprising two bird species, 8 crustaceans, 4 fishes, three plant species, two insects and two molluscs. Their diet was characterised specifically by intertidal crustaceans, occurring in 31.2% of all regurgitates, as well as plant material (30.1% of samples) and fishes. Silver Gulls were the only species with remains of fishing waste, with the remnants of Baldchin Groper occurring in one regurgitate.

The diet of Pacific Gulls consisted of 33 species; three species of birds, 16 species of crustaceans, six molluscs, two fish, one sea urchin and two plant species. Their diet was characterised predominately by intertidal crustaceans (59.1% of samples including shore, reef and hermit crabs as well as mantis shrimp), plant material (24.7% of samples) and cephalopods (22.6%). Their diet reflects a foraging habit along shorelines and reef flats during low tide. Table 3.7 is a summary of other dietary items recorded from Pacific Gull anvil sites. Interestingly, gastropod molluscs are more dominant at these sites, reflecting the lack of hard parts regurgitated from these prey types in the pellets of Pacific Gulls. Of the 167 prey items recovered from anvil sites, 82 (49.1%) were Turban Shells (*Turbo pulcher*), 23 (13.8%) were Shame-faced Crabs (*Calappa sp.*) and 22 (13.2%) were Baler Shells (*Melo amphora*).

Table 3.6: The contents of regurgitated pellets from Silver Gulls, Pacific Gulls and Pied Cormorants collected from the Houtman Abrolhos in 2014. N = total number of items of each prey type identified, F = Frequency of occurrence of each prey type (%).

	Pacific Gull		Silver Gull		Pied Cormorant	
Species	**N**	**F**	**N**	**F**	**N**	**F**
Aves						
Anous stolidus			7	8.9		
Anous tenuirostris			1	1.3		
Ardenna pacifica	1	1.1				
Pelagodroma marina	1	1.1				
Puffinus assimilis	1	1.1				
Unid	2	2.2	1	1.3		
Crustacea						
Odontodactylus sp.	4	4.3	13	9.7		
Dardanus sp.	1	1.1				
Calappa sp.	8	4.3				
Leptograpsus variegatus	18	11.8	6	6.4		
Thalamita sima	13	5.4	10	10.3		
Trizopagurus strigmanus	5	5.4				
Crab sp 3	3	2.2				
Portunas sp.	7	2.2				
Crab sp 5	3	3.2				
Nectocarcinus tuberculosus	4	4.3				
Crab sp 7			1	1.3		
Crab sp 8	3	2.2				
Ozius truncatus	18	4.3				
Crab sp 10	2	2.2				
Crab sp 11			1	1.3		
Crab sp 12			5	2.6		
Crab sp 13			3	1.3		
Crab sp 14	4	3.2				
Crab sp 15	3	2.2	1	1.3		
Crab sp 16	1	1.1				
Unid			6	3.9		
Osteichthyes						
Choerodon rubescens			1	1.3		
Scaridae sp1	2	2.2	10	7.7	12	20.0
Scaridae sp2			1	1.3	6	7.5
Scaridae sp3					6	10.0
Scaridae sp4					2	2.5
Labridae sp1					3	5.0
Labridae sp2					2	5.0
Labridae unid	2	2.2	3	2.6		

	Pacific Gull		Silver Gull		Pied Cormorant	
Species	**N**	**F**	**N**	**F**	**N**	**F**
Unid sp1					2	2.5
Unid sp2					1	2.5
Unid	11	11	10	10.3	16	32.5
Mollusca						
Gastropoda						
Ornithochiton quercinus	2	2.2				
Tectus Pyramus	32	8.6				
Turbo pulcher	12	5.4				
Unid					1	2.5
Cephalopoda						
Octopus sp.	2	2.2				
Sepiateuthis australis	9	4.3	1	1.3		
Sepia apama	1	1.1				
Unid	14	15.0	1	1.3	3	5.0
Echinoidea						
Tripneustes gratilla	1	1.1				
Insecta						
Coleoptera			5	4		
Dermaptera			4	2		
Plantae						
Myoporum insulare	211	4.3	181	7.7		
Nitraria billardierei	461	20.4	289	28.2		
Atropa belladonna			1925	25.6		
Plastics			1	1.3		

Figure 3.3: Diet composition by class of (a) Silver Gull, (b) Pacific Gull and (c) Pied Cormorant at the Houtman Abrolhos during 2014.

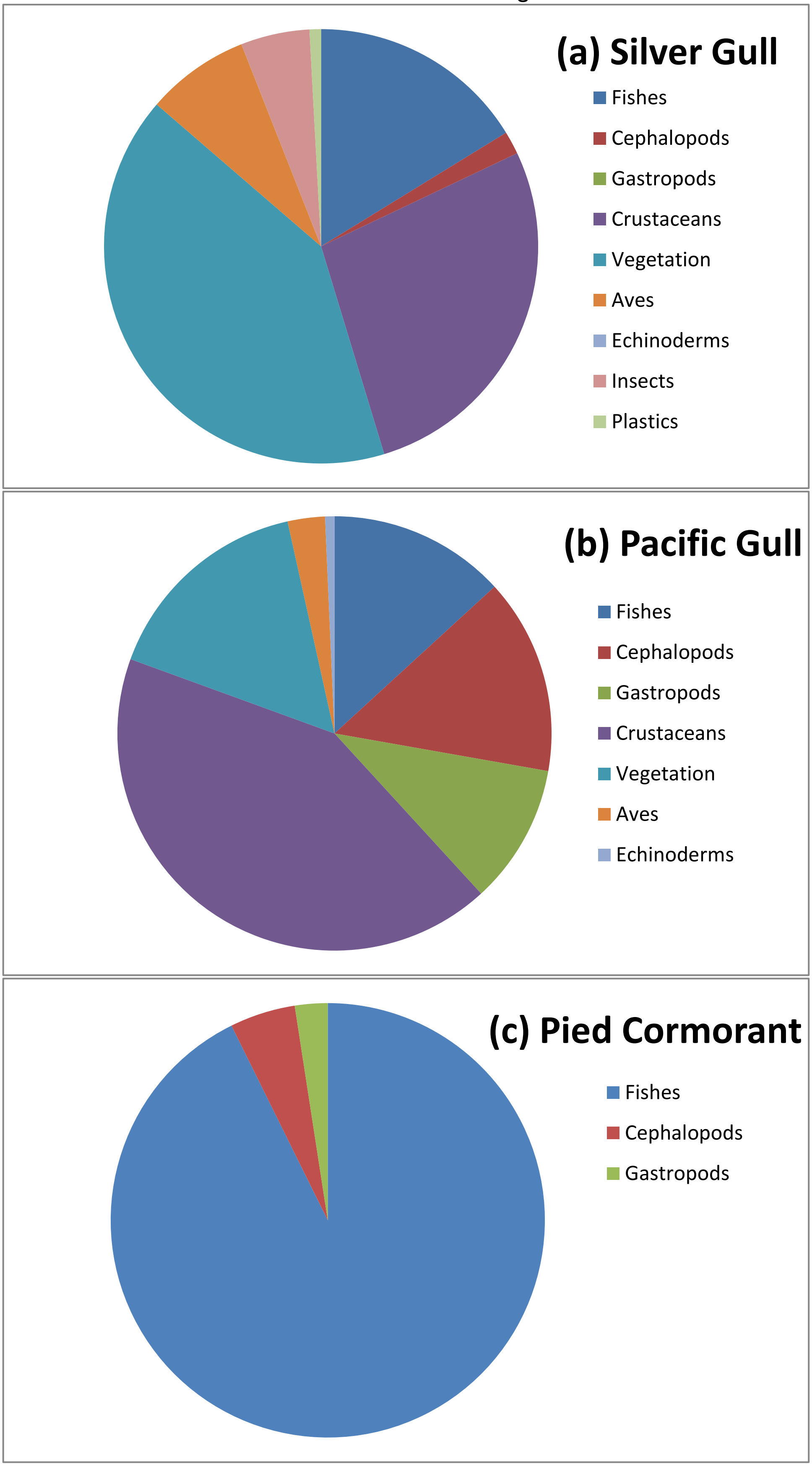


Table 3.7: Diet composition of the Pacific Gull collected from anvil sites at the Houtman Abrolhos during 2014.

	Animalia													Plantae
Island	Mollusca				Crustacea			Echinodermata		Chordata				
	Gastropoda				Cephalopoda	Decapoda			Echinoidea		Osteichthyes			
	Tectus	*Turbo*	*Cymatium*	*Melo*	*Unid.*	*Calappa*	*Leptograpsus*	*Dardanus*	*Tripneustes*	*Echinometra*	*Scomber*	*Choerodon*	*Unid*	*Nitraria*
Easter Group	*Pyramus*	*pulcher*	*mundum*	*amphora*		*sp.*	*sp.*	*sp.*	*gratilla*	*mathaei*	*sp.*	*rubescens*		
Alexander	8	9	0	0	0	0	0	0	0	0	0	0	0	0
Bynoe	0	2	0	0	0	0	0	0	0	0	0	0	0	0
Dry	2	2	0	0	0	0	0	0	0	0	0	0	0	0
Eight	2	2	0	2	0	0	0	0	0	0	0	0	0	0
Gibson	2	0	1	0	2	0	0	0	0	0	0	1	0	0
Helms	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Leo	0	0	0	0	0	1	0	0	0	0	0	0	0	1
Little Rat	3	3	0	0	0	0	0	0	0	0	0	0	0	0
Little Stokes	1	0	0	0	0	1	0	0	0	0	0	0	0	1
Rat	8	0	0	0	0	0	0	0	1	0	0	0	0	0
Shearwater Islet	3	15	0	0	0	0	0	0	0	0	0	0	0	0
Pelsaert Group														
Basile 1	3	12	0	0	0	0	0	0	0	0	1	0	0	0
Basile 2	0	11	0	0	0	0	0	0	0	0	0	0	0	0
Davis	0	1	0	3	0	20	0	0	0	0	0	0	0	0
Gun	2	6	0	0	1	0	0	0	0	0	0	0	0	0
Lagoon	5	0	0	0	0	0	0	0	0	0	0	0	0	0
One	5	2	0	8	0	0	0	0	0	0	0	0	0	0
Pelsaert 1	0	0	0	0	1	0	1	1	4	2	0	0	1	0
Pelsaert 2	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Sid Liddon	0	2	0	2	0	0	0	0	0	0	0	0	0	0
Sweet	2	5	0	7	0	1	0	0	0	0	0	0	0	0
Travia middle	0	10	0	0	0	0	0	0	0	0	0	0	0	0
TOTAL	**46**	**82**	**1**	**22**	**4**	**23**	**2**	**1**	**6**	**2**	**1**	**1**	**1**	**4**

3.4 Assessment of foraging behaviour - Stable Isotope Analysis

The current isotopic niches of the three potential increaser seabirds Mantis Shrimp, Top Shell *Tectus* and Squid are plotted on Figure 3.4. Also plotted are $\delta^{13}C$ or $\delta^{15}N$ values from Sooty Terns and Flying Fish (Sooty Tern prey items) from the regional oceanic food-chain (J.N. Dunlop unpublished data) to put the Abrolhos littoral ecosystem into its wider marine context. The $\delta^{13}C$ or $\delta^{15}N$ values for the dominant terrestrial ant on the Abrolhos Islands (*Polyrachis ammonoeides*, Dunlop *et al.* 2013) are also included to provide the isotopic niche of a terrestrial omnivore.

The $\delta^{13}C$ or $\delta^{15}N$ values for the gull mollusc, crustacean and cephalopod prey items from the gull pellets are consistent with these prey being taken from oligotrophic waters with much of the carbon (energy) coming from seagrasses (Smit *et al.* 2005, Hyndes & Lavery 2005) and probably from corals. The $\delta^{13}C$ or $\delta^{15}N$ values in flying-fish and Sooty Terns show the depleted $C^{13}$and slightly more enriched N^{15} (more productive) values for the adjacent oceanic waters.

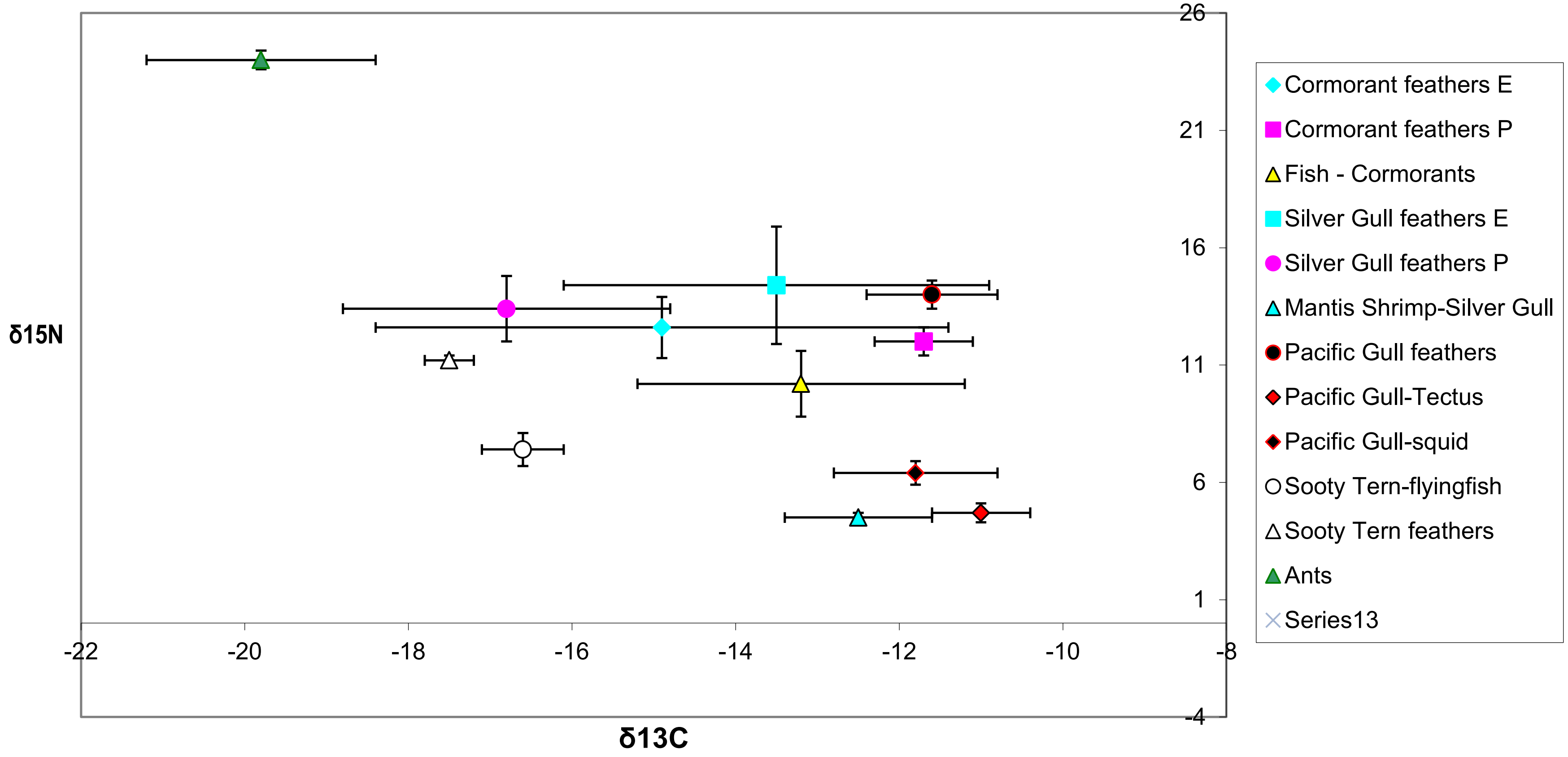
The fish samples taken from cormorants indicate a similar foraging environment (perhaps with some carbon coming from benthic algae) but the fish prey were feeding at a higher trophic level. Pied Cormorants in the Easter Group are evidently foraging over a wider range habitats than those from the Pelsaert Group, including more areas where the carbon is coming from macro-algae and /or phytoplankton.

The pellet analysis shows that the diet of Pied Cormorants is almost entirely fish and the nitrogen stable isotope ratios in the Cormorant feathers were effectively one trophic level above the prey sampled. The Gulls however were observed to have diverse diets and the feather samples were around two trophic levels higher than the prey (Mantis Shell, Top Shell and Cephalapods) sampled from the pellets. These prey with hard body parts are probably over-represented in pellets and fish of greater importance. Silver Gulls have slightly lower trophic levels than Pacific Gulls probably indicating the larger gull's raptorial behaviour (e.g. as a predator of other seabirds, and scavenger of dead predators). This would also raise the $\delta^{15}N$ values relative to the prey sampled from their pellets.

The high $\delta^{15}N$ values and lower $\delta^{13}C$ in Silver Gull feathers relative to the pellet material sampled for SI analysis probably reflects the degree to which these opportunists supplement their marine diet with terrestrial material. The consumption of various berries and insects was observed in the dietary analysis and in the field. The terrestrial ecosystems of seabird islands have very high $\delta^{15}N$ baseline values due to the volatilization of ammonia from guano (note location of the ant signature on Figure 3.4).

This analysis of current foraging patterns indicates that all species may respond to any increased availability of fish in the fish-farming areas. The gulls, and particularly the Silver Gulls, are most likely to utilise any direct subsidy from fish feed.

Figure 3.4: The current isotopic niches (as represented by $\delta^{13}C$ or $\delta^{15}N$ values) of the three potential increaser seabirds the Pied Cormorant, Silver Gull and Pacific Gull taken from feather, mantis shrimp, trochus shell (*Tectus pyramis*) and squid samples at both the Easter (E) and Pelsaert (P) Groups. Isotope values from Sooty Terns and Ants from Rat Island are included as a comparison.



4 Prediction of behavioural and population responses

4.1 Foraging behaviour and potential interactions with Houtman Abrolhos seabirds: Cause effect flow diagrams for key threats.

The sections below outline cause effect pathways for six key groups of seabirds that have been identified as being potentially impacted from fin fish aquaculture at the Houtman Abrolhos, these are:

- Pied Cormorants
- Silver Gulls
- Pacific Gulls
- Wedge-tailed Shearwaters
- Neritic Terns
- Pelagic Foraging terns and noddies

4.1.1 Pied Cormorants

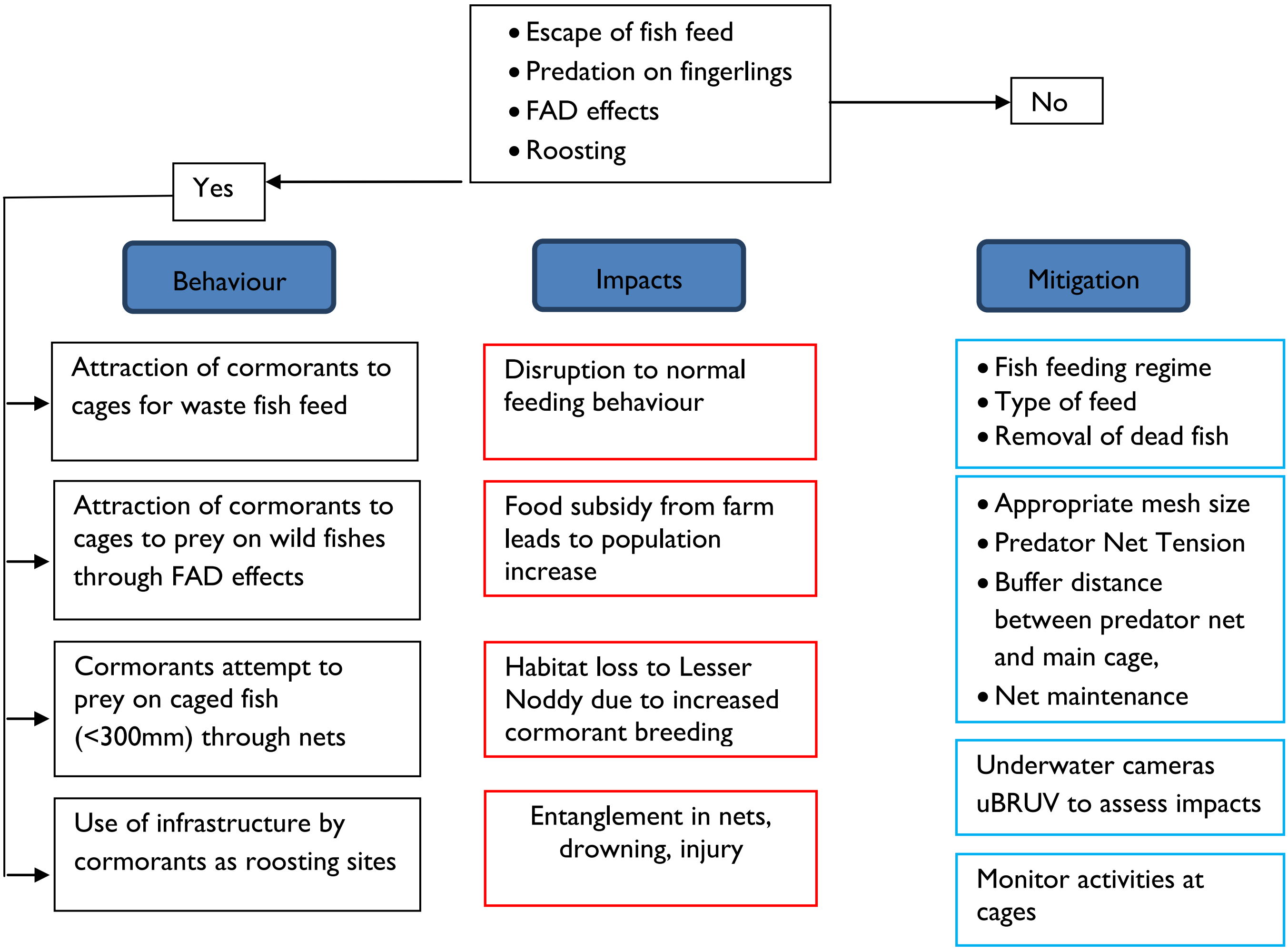
Conservation Status: Increasing in numbers in southern metropolitan coastal waters and possibly in Shark Bay Population: 1, 861 pairs, 1,222 Easter Group, 639 Pelsaert Group.

Approximately 1,861 pairs of Pied Cormorant nest throughout the Houtman Abrolhos, most on Wooded Island, however significant numbers (>500) are observed foraging regularly throughout the Pelsaert Group. Pied Cormorants have been observed foraging in the region of the Southern (Pelsaert Group) aquaculture site, and may continue to do so in relatively low numbers.

Pied Cormorants actively pursue fish prey underwater regularly attaining depths of 20 m or more. Moreover, Pied Cormorants are known to chase whole fishes from wetline vessels, and to enter rock-lobster pots in pursuit of small fishes attracted to the pots by bait. Beveridge (2001) identified cormorants as presenting the most likely seabird predator around sea cages in fish farms in Scotland. This species is likely to feed upon any cultured fish available that are less that 300mm long, as well as on fish prey attracted to sea cages through FAD effects and feed drift.

A risk associated with this activity is entanglement in the mesh of the walls of the cages, resulting in drowning. Mitigation would involve strict controls of excess fish food being allowed to escape the cages, regular maintenance of nets to repair holes and maintain tautness (Kemper *et al.* 2003, Pemberton 1996), and an appropriate mesh size (approximately 6cm, see Kemper *et al.* 2003).

Best management practices regarding maintenance of predator nets will reduce the risk of entanglement, as well as reduce predation of fish prey. However FAD effects of sea cages may result in an increase in food supply and feeding opportunities to Pied Cormorants, resulting in an increase in this species population size. Any increase in Pied Cormorant population size may result in more habitat loss for the threatened Lesser Noddy through nest site competition at mangroves in the Easter Group.


• Escape of fish feed
• Predation on fingerlings
• FAD effects
• Roosting
No
Yes
Behaviour
Impacts
Mitigation
Attraction of cormorants to cages for waste fish feed
Attraction of cormorants to cages to prey on wild fishes through FAD effects
Cormorants attempt to prey on caged fish (<300mm) through nets
Use of infrastructure by cormorants as roosting sites
Disruption to normal feeding behaviour
Food subsidy from farm leads to population increase
Habitat loss to Lesser Noddy due to increased cormorant breeding
Entanglement in nets, drowning, injury
• Fish feeding regime
• Type of feed
• Removal of dead fish
• Appropriate mesh size
• Predator Net Tension
• Buffer distance between predator net and main cage,
• Net maintenance
Underwater cameras uBRUV to assess impacts
Monitor activities at cages

4.1.2 Silver Gulls

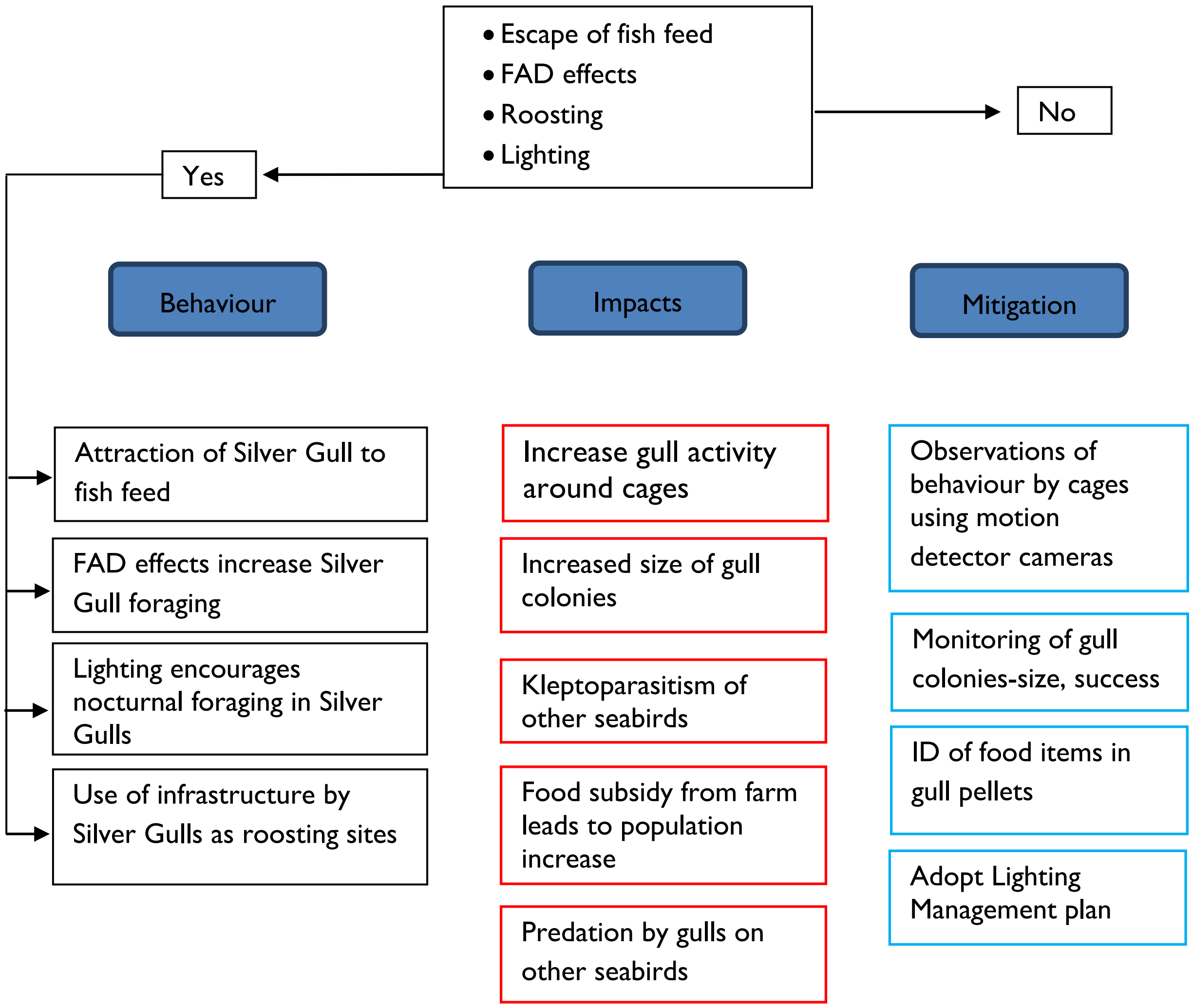
Conservation Status: Increased near major urban centres such as Perth and Albany and on islands near oil platforms

Population: Highly variable, 50-264 pairs. The current Silver Gull summer population is relatively small (~50 pairs), reflecting food availability (Nitre bush berries, seabird eggs and chicks, marine invertebrates) during the summer months. A larger breeding population (~ 150+ nests) once nested in the Pelsaert Group during the autumn, taking advantage of bait discards from A Zone rock-lobster boats and food scraps from fishing camps. There is a latent breeding population indicated by the large proportion of nest sites built without breeding attempts (110 of the 237 nests located across the two groups – see Table 3.3). Throughout Western Australia, higher numbers of Silver Gulls are often in association with refuse sites. The current breeding Silver Gull population at the Houtman Abrolhos is naturally very small.

Gulls elsewhere predate heavily on the eggs and young of other seabird species (Becker 1995) and will also kleptoparasitize other seabirds-and cormorants for their food (Stienen *et al.* 2001). The greatest risk for the proposed fish-farming development is an increase in the availability of food to the autumn breeding population of gulls and the flow on impacts to other seabirds nesting in the area.

Both gulls and fulmars adjusted their behaviour in line with fishery activities (Hamer *et al*. 1997, Oro *et al.* 1997). Discards from trawl fisheries increased the frequency of feeds provided to chicks and resulted in more successful breeding. In a largely fish eating gull species, discards from trawl fisheries accounted for 73% of the diet, having a dramatic effect of adult time budgets and chick provisioning rates. Increased availability of food for gulls across the North-west Shelf from gas flares over water has led to massive increases in gull populations with consequential displacement of other nesting seabirds and the predation of their young and eggs (L. Nicholson *pers comm*.) and hatchling turtles. The situation with the Silver Gull population explosion in response to the tuna pens at Port Lincoln was summarized in section 1.4, however access to fish food (pilchards) allowed the Silver Gull to expand its breeding season (now parallels the tuna ranching season), increase their reproductive output (per pair) and exponentially increasing its local breeding population from 3,300 pairs in 1999 to 27,800 pairs in 2005 (Harrison 2010).

Unlike Pied Cormorants, Silver Gulls cannot dive for prey, therefore access to young fish, or pelletised food is likely to be at the surface. However, the FAD effects of sea cages may present a foraging opportunity, particularly if lights are used at night aggregating zooplankton.


Escape of fish feed
FAD effects
Roosting
Lighting
No
Yes
Behaviour
Impacts
Mitigation
Attraction of Silver Gull to fish feed
FAD effects increase Silver Gull foraging
Lighting encourages nocturnal foraging in Silver Gulls
Use of infrastructure by Silver Gulls as roosting sites
Increase gull activity around cages
Increased size of gull colonies
Kleptoparasitism of other seabirds
Food subsidy from farm leads to population increase
Predation by gulls on other seabirds
Observations of behaviour by cages using motion detector cameras
Monitoring of gull colonies-size, success
ID of food items in gull pellets
Adopt Lighting Management plan

4.1.3 Pacific Gulls

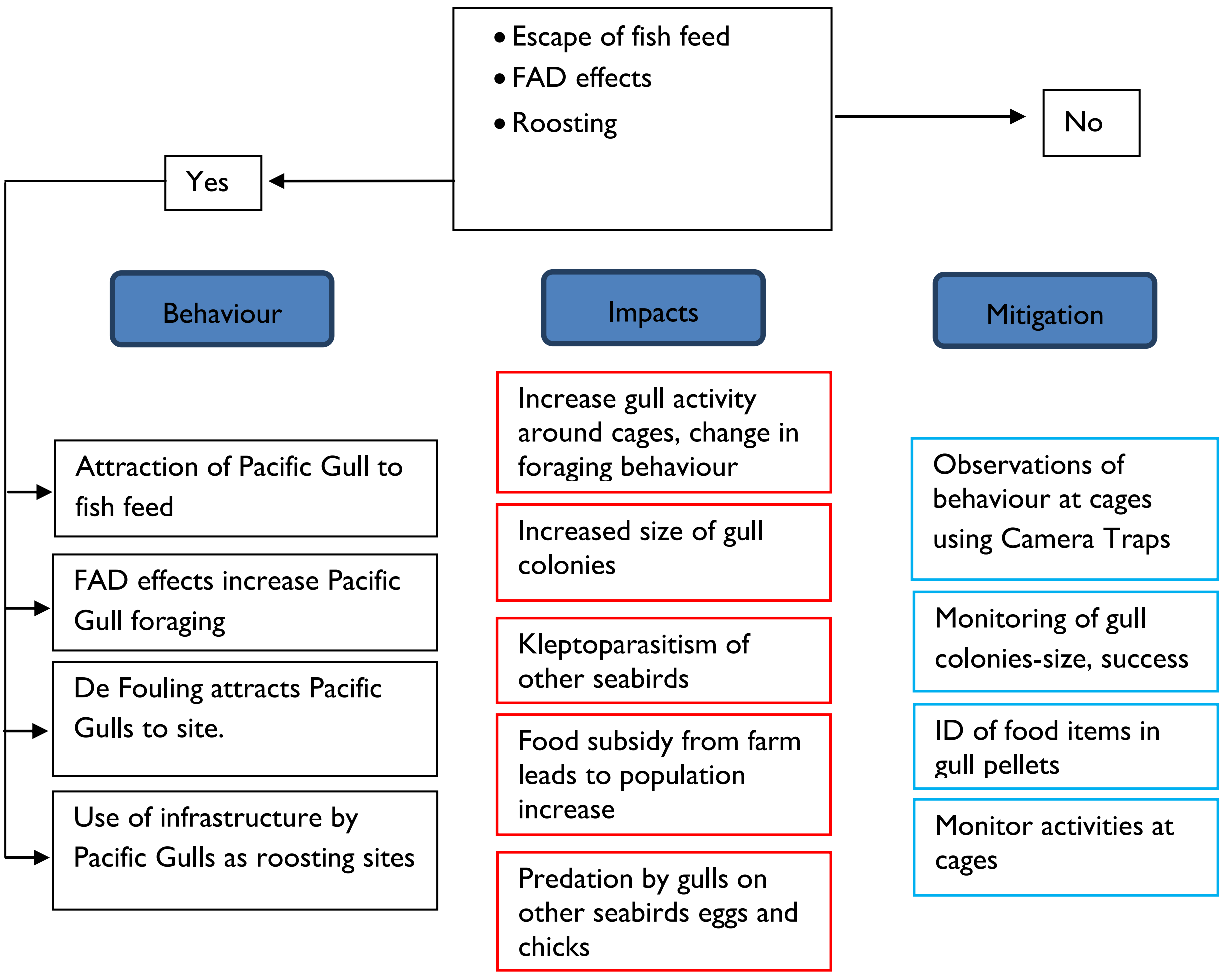
Conservation Status: Considered near threatened with a small and possibly genetically distinct west coast population.

Population: Highly variable, 50-264 pairs.

The Houtman Abrolhos represents the largest population of Pacific Gulls *Larus pacificus* along the Western Australian coast. Currently there are 74 active pairs of Pacific Gulls across the Easter and Pelsaert Groups at the Houtman Abrolhos (Table 3.4). Previously we recorded 127 Pacific Gulls (Surman and Nicholson 2009a). Elsewhere this species is threatened by displacement by the successful scavenging gull the Kelp Gull *Larus dominicanus*. Almost half of all Pacific Gulls found at the Houtman Abrolhos nest within the Pelsaert Group (Fuller *et al.* 1994).

Pacific Gulls are predominately predatory, foraging on reef flats at low tide on whelks, trochus shells, turbo shells, baler shells, mantis shrimps, cuttlefish, octopuses and crabs. However, during the previous seasonal Zone A rock lobster fishing season they scavenged for bait scraps from fishing boats and upon fish frames from wet line boats and other areas where fish are cleaned.

Impacts from an increase in food availability include the replacement of predatory behaviour for scavenging behaviour in this species. These impacts however, may provide a net positive increase for the Pacific Gull population given that it is so small. However, over the longer term, population increases in such a large species may not be sustainable and increases based on available food during the summer may have negative population impacts during other times of the year. Predation rates on other seabird species eggs and chicks and in particularly adult Storm-petrels may increase.



4.1.4 Wedge-tailed Shearwaters.

Conservation Status: EPBC Marine and Migratory.
Population: 1.1 million pairs.

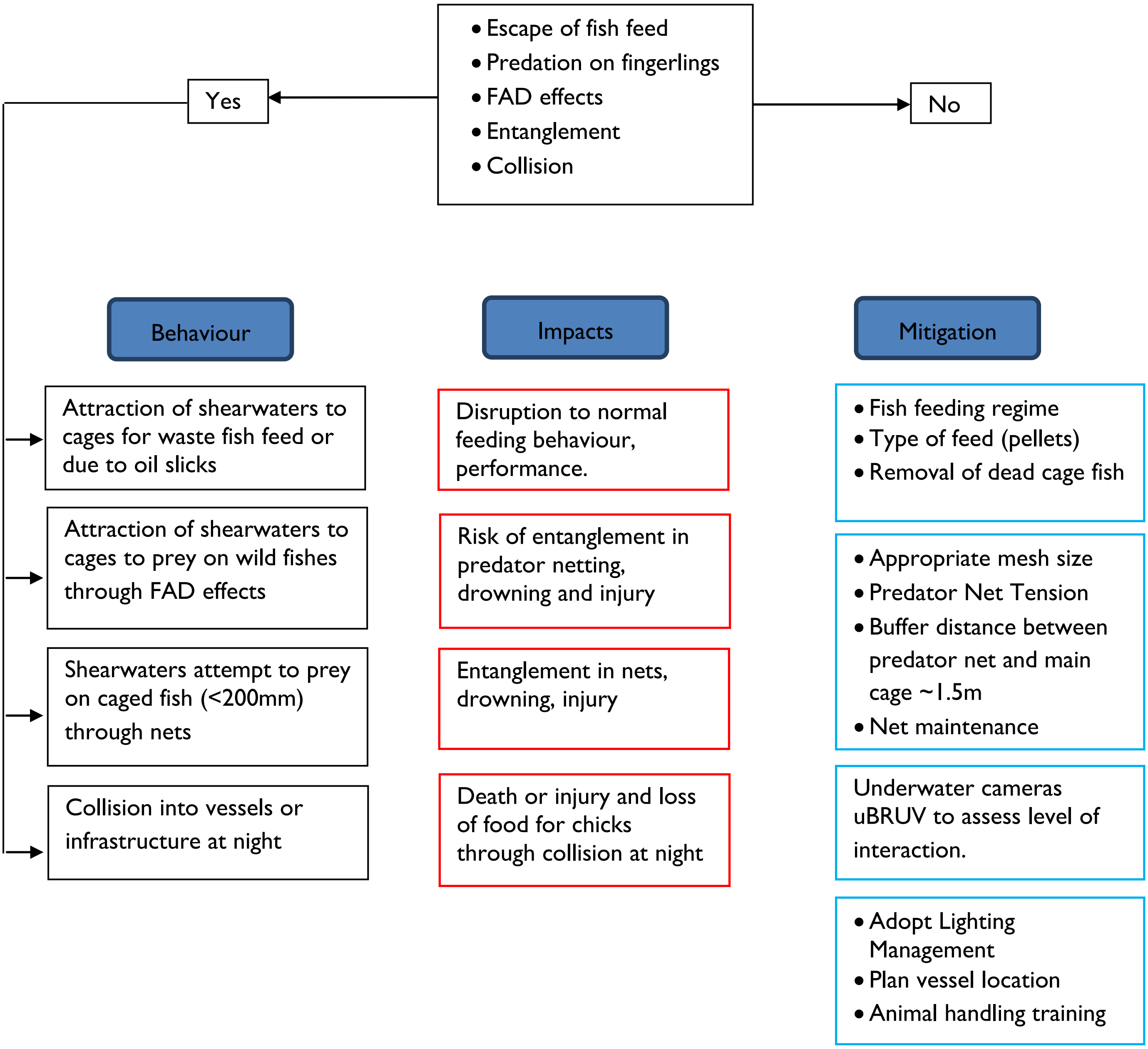
Wedge-tailed Shearwaters *Ardenna pacifica* is the most populous seabird nesting at the Houtman Abrolhos. Current estimates indicate a population of 2.2 million birds scattered over 11 islands, most on Pelsaert (160 000) and West Wallabi (2 million). As with the majority of seabirds, they return to the Houtman Abrolhos in August and breed over the summer months before their young fledge in May. The Abrolhos populations are significant at a national level.

Wedge-tailed Shearwaters pursue their prey actively underwater, and are capable of reaching depths of between 3-66m (Burger 2001). This allows them access to any fish feed on the surface, below the cages or seeping from cage walls. These shearwaters accompany operating lobster boats scavenging bait discards and capturing animals exiting through the escape gaps of pots during pulling. They would be capable of foraging in and out of the nets, as well as below the cages for any fish scraps. In doing so they may potentially be entangled in the mesh of the cages and drown. Wedge-tailed Shearwaters are also vulnerable to collision as they forage at night and commute to and from the colony under the cover of darkness. Shearwaters are often disorientated by lighting, resulting in collisions and injury or death. Mooring of any vessels overnight on site will require stringent light management protocols for part of the year.

Heffernan (1999) found that diving seabirds in the northern hemisphere, like puffins and guillemots, visit fish farms to feed upon increased wild fishes attracted to sea cages (i.e. the FAD effect). Wedge-tailed Shearwaters have been observed foraging regularly in the Middle Channel and Geelvink Channel in the vicinity of the proposed aquaculture leases, although these are not regarded as the major foraging sites. However this species forages on prey (i.e. Scaly Mackerel, Slender Sprat – see Gaughan *et al.* 2002) that are likely to aggregate around sea cages, and if attracted May potentially become entangled. They are also known to be attracted by oil slicks from sea cages, and dead fish.

Wedge-tailed Shearwaters are also known to undergo high variability in their reproductive success due to natural variability in marine productivity (Dunlop *et al.* 2002) that may be measured through growth rates in chicks (Petit *et al.* 1984). They consume large amounts (1000's of tonnes pa) of Scaly Mackerel *Sardinella lemura* and squids (Gaughan *et al.* 2002).

Best management practices regarding maintenance of anti-predator nets as outlined by Sagar (2013 and Kemper et al. 2003) will reduce the risk of entanglement of diving shearwaters, as well as reduce predation upon smaller cultured fish prey. These are listed in Table 4.1, and in Table 4.5.


• Escape of fish feed
• Predation on fingerlings
• FAD effects
• Entanglement
• Collision
Yes
No
Behaviour
Impacts
Mitigation
Attraction of shearwaters to cages for waste fish feed or due to oil slicks
Attraction of shearwaters to cages to prey on wild fishes through FAD effects
Shearwaters attempt to prey on caged fish (<200mm) through nets
Collision into vessels or infrastructure at night
Disruption to normal feeding behaviour, performance.
Risk of entanglement in predator netting, drowning and injury
Entanglement in nets, drowning, injury
Death or injury and loss of food for chicks through collision at night
• Fish feeding regime
• Type of feed (pellets)
• Removal of dead cage fish
• Appropriate mesh size
• Predator Net Tension
• Buffer distance between predator net and main cage ~1.5m
• Net maintenance
Underwater cameras uBRUV to assess level of interaction.
• Adopt Lighting Management
• Plan vessel location
• Animal handling training

4.1.5 Neritic Terns

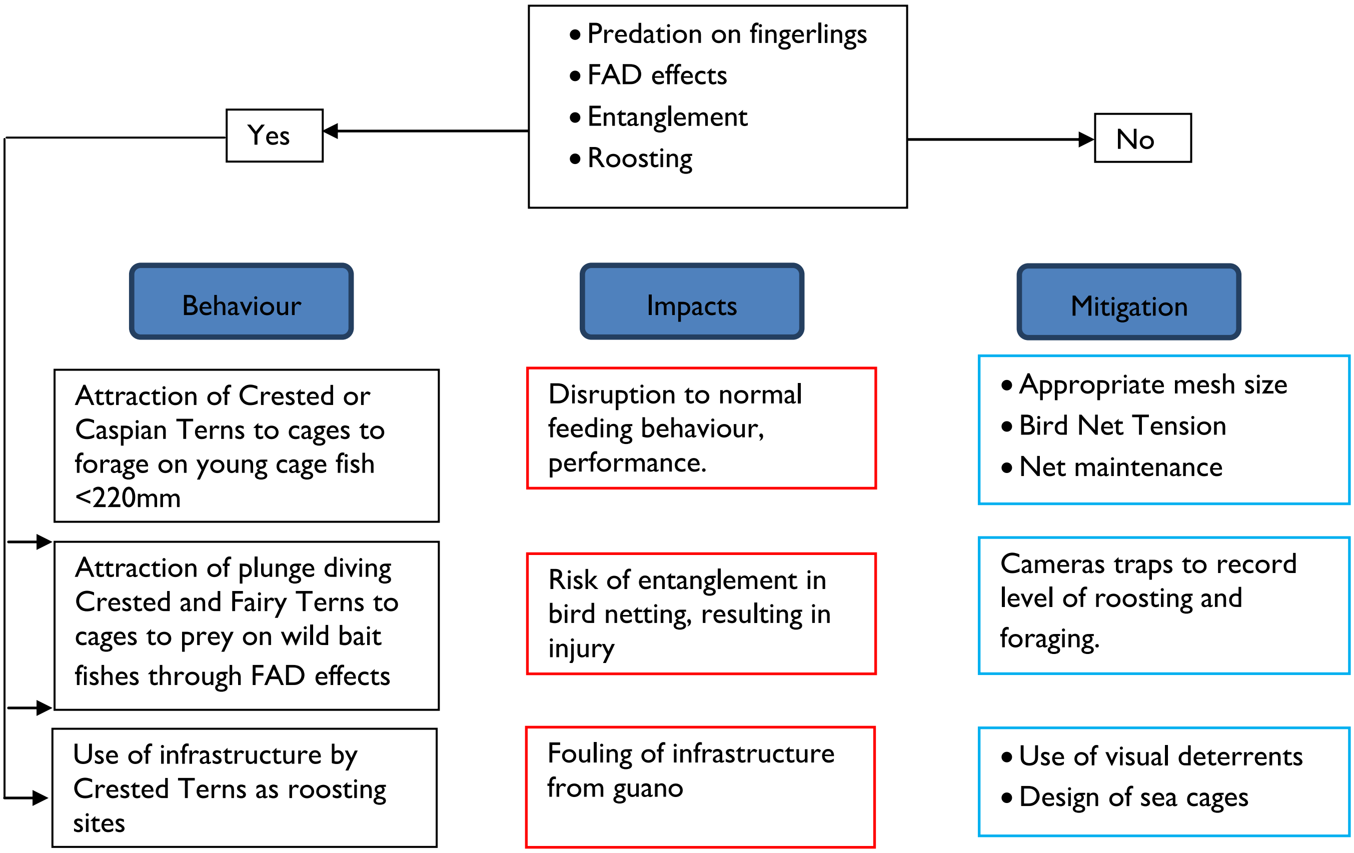
Conservation Status: EPBC Marine and Migratory (Fairy Tern Threatened).
Populations: Crested Tern ~3000 pairs.
Caspian Tern ~70 pairs
Fairy Tern ~550 pairs.

Neritic terns are those tern species that in part forage over shallow waters adjacent to coasts or islands. At the Houtman Abrolhos these comprise Crested, Fairy, and Caspian Terns. These birds are plunge-divers, which can reach depths of 1 m or so in pursuit of schooling bait fishes.

Crested Terns nest in colonies of up to 1000 pairs throughout the Houtman Abrolhos (Fuller *et al*. 1994, Surman and Nicholson 2009a) with half the population nesting within the Pelsaert Group. Crested Terns feed predominately upon schools of small-medium sized schooling fishes over shelf waters. At the Houtman Abrolhos their preferred prey are Scaly Mackerel *Sardinella lemura* (Surman and Wooller 2003). Of the 4300 Crested Terns nesting at the Houtman Abrolhos, 52 % are on the Pelsaert Group. Fairy Terns also nest in colonies from a few pairs to several hundred pairs. They feed predominately upon small fishes, particularly slender sprat (*Spratelloides gracillis*), juvenile black-spotted goatfish (*Parupeneus signatus*) and hardyheads (Atherinidae). The large Caspian Tern feeds almost exclusively over shallow reef flats on wrasses, blennys, mullet, whiting and gobies.

Crested Terns are likely to be influenced by the presence of fishes in cages, and may also feed in cages if sea cages are not covered. Fairy Terns are more likely to feed upon small surface fishes attracted to sea cages through FAD effects.

Fairy Terns nest in large colonies in the Easter and Pelsaert Groups and plunge dive for smaller, schooling fishes including post larval Mullids and hardyheads (Atherinids). They may be attracted to fish schools aggregated around the pens from time to time.

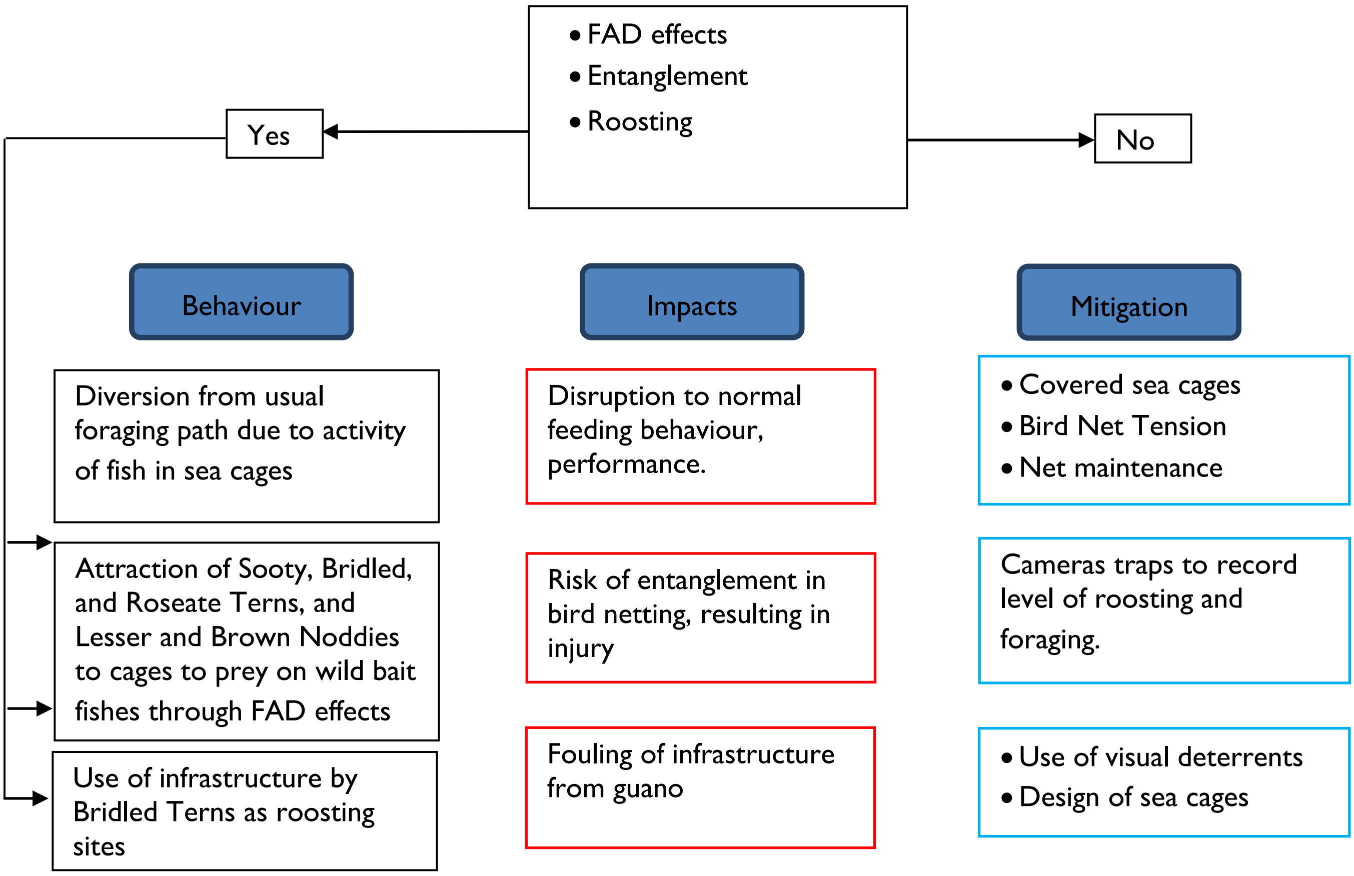

• Predation on fingerlings
• FAD effects
• Entanglement
• Roosting
Yes
No
Behaviour
Impacts
Mitigation
Attraction of Crested or Caspian Terns to cages to forage on young cage fish <220mm
Attraction of plunge diving Crested and Fairy Terns to cages to prey on wild bait fishes through FAD effects
Use of infrastructure by Crested Terns as roosting sites
Disruption to normal feeding behaviour, performance.
Risk of entanglement in bird netting, resulting in injury
Fouling of infrastructure from guano
• Appropriate mesh size
• Bird Net Tension
• Net maintenance
Cameras traps to record level of roosting and foraging.
• Use of visual deterrents
• Design of sea cages

4.1.6 Pelagic foraging terns and noddies

Conservation Status: EPBC Marine and Migratory (Lesser Noddy Threatened).
Populations: Lesser Noddy 34500 pairs.
Brown Noddy 132000 pairs
Sooty Tern ~200000 pairs.
Roseate Tern 4210 pairs
Bridled Tern ~7000 pairs

Sooty Terns *Onychoprion fuscata*, Brown Noddies *Anous stolidus* and Lesser Noddies *A. tenuirostris* form a large community of breeding seabirds at the southern end of Pelsaert Island. There are 260 000 Sooty Terns (65 % of total Abrolhos population), 264 000 Brown Noddies (100 % of total) and 45 000 Lesser Noddies (65 % of total) breeding over summer at the Pelsaert Group. These seabirds feed in association with predatory fishes (i.e. tunas) as well as over large schools of larval fishes and squids across both shelf and oceanic waters at least 150km west of the Houtman Abrolhos (Surman *pers. obs*.).

Large numbers of Sooty Terns and Brown Noddies may pass over the proposed fish farm, and may be influenced by activity of the fishes in the cages and diverted from their normal flight paths and foraging trips. Bridled Terns *Onychoprion anaethetus* occur in the area in lower densities but will use any floating objects to rest upon, and may also forage upon aggregations of baitfishes associated with the sea cages. Mixed flocks of seabirds (Roseate Terns, Bridled Terns, Crested Terns and Wedge-tailed Shearwaters) have been recorded foraging in the area in association with skipjack tuna and bronze whaler sharks.



4.2 Risk & Mitigation Assessment

In Table (4.1) all the potential adverse interactions (risks) between seabirds and sea cage fish-farming at the Abrolhos Islands are identified together with the available 'best practice' mitigation measures. It is assumed that all the relevant wildlife mitigation measures outlined in the Department's ' Representation of Aquaculture Operations' will be adopted by any proponent from the outset.

Table 4.1: Seabird Interaction Risk Mitigation at Floating Pen Fish Farms at the Houtman Abrolhos Islands.

Factor	Interaction	Potential Consequence	Available Mitigation Methods
1. Pen Location	Attraction: • Seabirds attracted to pens from colonies on the Houtman Abrolhos Islands. • Seabirds distracted from normal flight path by fish activity adjacent sea cages or within sea cages.	• Changes in seabird behaviour or energetics, changing reproductive performance or increasing mortality • Changes in seabird population sizes leading to increased interspecific competition, kleptoparisitism, predation of eggs and young and habitat alteration on the Houtman Abrolhos Islands. • Shifts in terrestrial ecosystems driven by changes in breeding seabird numbers.	• All locations are within foraging range of all seabird breeding species. Choice between proposed fish-farming zones on this scale is unlikely to reduce potential for interactions.
2. Fish - feed	Fish feed is available to foraging seabirds providing an energy / nutrient subsidy, this is less likely if pelletised feed is used. Species likely to exploit fish food are gulls and cormorants.	• Increasing populations of potential increaser species (Silver Gulls, Pacific Gulls and Pied Cormorants) leading to ecological changes (see 1 above). • Increase Pied Cormorant populations will reduce nesting habitat for Lesser Noddies on Wooded Island. • Increased gull populations may impact other nesting seabirds through predation and competition.	• Pellets preferred over whole fish. • Sub-surface, slow release feeders. • Current speeds not sufficient to allow lateral export of feed through meshes. • Complete pen coverage with bird mesh. • Submersible sea-cages
3.Cultured fish size	• Seabirds attracted to forage on farmed stock within their preferred prey size ranges. • Seabirds distracted by large schooling species associated with mixed species foraging aggregations.	• Increasing populations of both gulls and cormorants leading to ecological changes (see 2 above). • Loss of cultured stock. • Reduced foraging efficiency reducing reproductive performance. • Risk of entanglement in anti-predator netting.	• Complete pen coverage with bird mesh. • Submersible sea-cages. • Anti-predator nets with appropriate mesh size for seabirds (6cm) • Space between anti predator net and sea cage ~1.5m.
4. Sea-pen diameter	Interactions with aerial-snatch predators (e.g. Sea-Eagles & Ospreys) will increase with pen diameter.	• Loss of farmed stock, and redistribution or increased abundance of marine raptors.	• Complete pen coverage with bird mesh. • Limit diameter of sea-cages. • Submersible sea-cages
5. Raft characteristics	Some seabirds (e.g. Bridled Terns, gulls) preferentially perch on flotsam	• Faeces from birds may reduce water quality, transfer pathogens / parasites to stock.	• Complete pen coverage with bird mesh. • Design of railings, floats, net-rings to reduce

Factor	Interaction	Potential Consequence	Available Mitigation Methods
	or floating objects and may utilise sea-cages as roosts.	• Collisions with structures or entanglement with nets. • Fouling of gear. • Negative interactions from staff towards native fauna	perching. • Alternative artificial rafts. • Submersible sea-cages • Bird Deterrents (Visual, audio, physical)
6. FAD effects	Attraction of larval fish and crustaceans, bait fishes and predatory fishes due to FAD effects of superstructures.	• Seabirds may concentrate around fish farms increasing potentially adverse interactions (see 1 above). • Increased foraging opportunities for some species (increaser species). • Increased risk of entanglement from foraging seabirds	• FAD effects are likely to increase with distance from reefs. • Alternative artificial rafts or reefs. • Mesh sizes.
7. Fish oil slicks	Oily residues from stock and feed will form slicks which draw-in forage fishes (enhancing FAD effect) and seabirds (particularly olfactory foragers such as shearwaters and storm-petrels).	• Seabirds may concentrate around fish farms increasing potentially adverse interactions (see 1 above). • Increased foraging opportunities for some species (increaser species). • Increased risk of entanglement from foraging seabirds, particularly diving species.	• Reduce oil content /production of feeds. • Remove dead fish from cage
8. Superstructure and predator nets	Structures including netting above and below the water surface may entrap or entangle foraging or roosting seabirds.	• Increased mortality particularly among pursuit diving species, e.g. cormorants and shearwaters. • Potential entanglement from Osprey and White-breasted Sea Eagles.	• Appropriate mesh sizes, visibility and net tension. • Regular net checks and maintenance • Camera trap monitoring • uBRUV monitoring
9. Lighting	• Many seabirds fly at night and are disorientated by bright navigation or vessel flood-lights. • Lights may also attract zooplankton further increasing the FAD effect of sea-cages allowing gulls to feed at night	• Increased seabird mortality from collisions with super structure of cages and moored vessels. • Enhanced prey aggregation around fish-farms may increase adverse interactions with seabirds. • Enhanced food supply for increaser species, Silver Gulls are known to forage under lights at night.	• Development of lighting management plan • Design of light horizon and wavelength. • Reduction in use of lighting. • Seasonal lighting reduction policies.
10.Moored Vessels	• Accommodation and farm vessels	• Increased seabird mortality from collisions (see 9 above).	• Development of lighting management plan

Factor	Interaction	Potential Consequence	Available Mitigation Methods
	on site increase collision and disorientation risks to seabirds. • Moored vessels provide roosts for seabirds • Vessel wastes may attract increaser species. • Increased boating traffic may deter natural foraging behaviour.	• Loss of food for seabird young from adults regurgitating after collision or disorientation on vessel. • Enhanced food supply for increaser species, Silver Gulls are known to forage under lights at night or on waste from vessels (food scraps, bait, and offal).	• Design of light horizon and wavelength. • Management plan for reducing impacts from collision • Training for bird handling and reporting • Reduction in use of lines or rigging across vessel • Mooring location outside of flight paths.
11.Marine Debris	Loss of lines, netting, plastics, floats or refuse from operations.	• Entanglement of marine fauna in portions of nets or lines lost from farm or over side of vessels (scuppers). • Ingestion of plastics from farm wastes, reduction in foraging efficiency and delivery of food to young.	• Waste management plan • Return of all waste to mainland • Maintenance of farm gear • Mesh over scuppers to prevent loss to sea.
12. Food Supplementation from de-fouling operations	Gulls that rely naturally on marine invertebrates may be attracted to operations removing encrustations	Food supplementation or entrapment	Collection of biological material for disposal away from aquaculture operations or burial.

References: Sagar (2013)

4.3 Risk assessment of direct and indirect impacts of the MWADZ proposal on seabirds

4.3.1 Context and scope

The current threat identification, hazard pathway analysis and risk assessment in relation to seabirds at the Houtman Abrolhos was conducted to identify and assess the potential impacts of finfish aquaculture on seabirds within of the MWADZ. Both the inherent risk (risk before application of management controls) coupled to the residual risk (following application of proposed management controls) were assessed in order to determine the nature and level of management controls required to bring the cumulative risks around sea-cage culture of finfish in the MWADZ to an acceptable level.

The assessment is based on applied knowledge and from the limited records relating to interaction between seabirds and culture of marine finfish (see Sagar 2008, 2013, Lloyd 2003, Pemberton 1996, Kemper *et al.* 2003 and Price and Morris 2013). The assessment has also considered all available relevant information relating to:

- the proposed location within the Abrolhos Islands' Fish habitat Protection Area (FHPA);
- Seabirds known to inhabit the FHPA in the vicinity of the MWADZ, and in particular the behavioural biology of each seabird species;
- the likely characteristics of yellow tail kingfish aquaculture (proposed aquaculture);
- Proposed management framework and options for minimising interactions between seabirds and the proposed aquaculture.

Information on interactions between seabirds and aquaculture is limited. However, this risk assessment was undertaken using the combined knowledge of 80 years of working with seabirds in the marine environment (Dr JN Dunlop, Dr LW Nicholson and Dr CA Surman), and for one of us (CAS) a total of 25 years of research conducted at the Houtman Abrolhos.

4.3.2 Hazard Pathway Analysis

Individual hazards as listed in Table 4.1 above were assessed with respect to their risk with respect to both inherent risk (i.e. baseline risk if no management measures aimed at mitigating the risk were in place) and residual risk (i.e. remaining risk once one or a number of proposed management controls have been effected). This process was undertaken to both understand the individual inherent hazards as well as to provide clarity as to the specific hazard or risk that a particular management activity is targeted at mitigating. This in turn assists in assessing whether management controls are adequate to manage risk of the entire pathway to an acceptable level and to identify any additional management actions required to address specific unacceptable risks.

In order to determine a quantifiable Risk Level (see Table 4.3 for definitions of Risk Levels), a consequence versus likelihood risk matrix for each potential threat was undertaken (Table 4.2, Fletcher 2014). We have chosen a 4x4 matrix for this analysis.

The consequence rating (1-4) is a measure of the outcome of an event that may impact the objectives, that is it is an arbitrary measure of the level of impact resulting from a threat. The Likelihood rating (1-4) is the probability of such an event occurring. The combined score of the consequence and likelihood rating is then used to determine the overall Risk Rating (Table 4.4) considered from the threat or impact. Definitions of both likelihood and consequence are presented in Table 4.3.

To facilitate the thought process of assessing potential threats to seabirds from aquaculture we have produced flow diagrams and descriptions of threat pathways for each of the main seabird species considered to be potentially impacted from fin fish aquaculture (see Section 4.1 above).

Table 4.2: Consequence versus likelihood risk matrix (after Fletcher 2014) for risk assessment for seabirds resulting from the MWADZ.

		Likelihood			
		Remote	Unlikely	Possible	Likely
Consequence		1	2	3	4
Minor	1	1	2	3	4
Major	2	2	4	6	8
Extreme	3	3	6	9	12
Minor	4	4	8	12	16

Table 4.3: Descriptions of likelihood and consequence indicators in relation to impacts to seabirds from the MWADZ (after Fletcher 2014).

Likelihood Level	**Likelihood descriptor**
Remote	A particular consequence level is unknown in such projects, but may still be plausible, probability 1-2%.
Unlikely	The consequence is not expected to occur within the lifetime of the project, probability of 3-9%.
Possible	A particular consequence level may occur within the lifetime of the project with a probability of 10-39%.
Likely	A particular consequence level is expected to occur within the time frame with a probability of 40-100%
Consequence Level	**Consequence descriptor**
Minor	Measureable but minimal impacts that are acceptable and meet objectives
Moderate	Maximum acceptable level of impacts that will still meet objectives.
Major	Above acceptable levels of impact with broad and/or long term negative effects on objective. Restoration may be achieved within a short to moderate time frame.
Extreme	Unacceptable level of impact. Serious effects upon objective with long or unobtainable restoration period.

Table 4.4: Levels of risk (and colour coding) and likely management responses and reporting requirements in relation to impacts to seabirds form the MWADZ (after Fletcher 2014).

Risk Level	Risk Score (Consequence vs. Likelihood)	Management Response	Expected Management/Mitigation Requirements
Negligible (0)	0-2	Acceptable; no specific control measures needed	None specific
Low (1)	3-4	Acceptable; with current risk control measures in place (no new management required)	Specific management and/or monitoring required
Moderate (2)	6-8	Not desirable; continue strong management actions OR new and/or further risk control measures to be introduced in near future	Increases to management activities needed
High (3)	9-16	Unacceptable; major changes required to management in immediate future	Increases to management activities needed urgently

4.3.3 Hazard Analysis: Potential negative effects of aquaculture on Seabirds

Table 4.5. Assessment of hazards to seabirds. Hazards were individually analysed with respect to both the inherent hazard (i.e. baseline hazard if no management measures aimed at mitigating the hazard were in place) and their residual hazard (i.e. remaining hazard once one or a number of the proposed management controls have been implemented). Please refer to Table 4.1 for details on interactions, consequences and mitigation methods for each identified Hazard.

Hazard (see Table 4.1 for details)	**Inherent Hazard Assuming No Management Controls**	**Justification**	**Residual Hazard Following Implementation Of Management Controls**	**Justification And Identified Management Controls** (See Section 4.1 for details).
1 Entanglement. Seabirds becoming entangled in sea cage netting, bird netting or anti predator netting during foraging or roosting, causing drowning.	Likelihood Likely (4) Consequence Moderate (3) Hazard Score (12) Risk Level (3) **High**	***Consequence: Moderate.*** *More than a few individuals impacted particularly EPBC protected diving species (Shearwaters) as well as Pied Cormorants* ***Likelihood: Likely***. *Certain that without management measures seabirds will become entangled.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor***. *A few individuals may be impacted in each year* ***Likelihood: Possible.*** *Occasional entanglement may occur even with best practices.* ***Management Controls***: • *Appropriate net maintenance including net tension* • *Spacing between predator net and sea cage (1.5m)* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions i.e. uBRUV and*

				Camera Trap monitoring
2. Food Subsidy from fish feed. Gulls or cormorants receiving food subsidy from sea cages and increasing population size. Increase in gull or cormorant numbers impacting upon eggs and young of other seabird species including EPBC listed species.	Likelihood Likely (4) Consequence Major (3) Hazard Score (12) Risk Level (3) **High**	***Consequence: Major*** *Recovery of a vulnerable population impeded (Lesser Noddies), ecosystem altered through increase in gull or cormorant numbers.* ***Likelihood: Likely*** *Certain that without management measures gulls and cormorants will exploit fish fee and respond with increase in breeding populations.*	Likelihood Unlikely (2) Consequence Minor (1) Hazard Score (2) Risk Level (0) **Negligible**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Unlikely*** *Not expected to occur, but may occur under special circumstances.* ***Management Controls**:* • *Fish fed pelletized food* • *Feed rate controlled to prevent escape of feed for sea cages* • *Appropriate bird netting and maintenance including net tension* • *Appropriate anti-predator netting mesh size and spacing.* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring.*
3. Attraction due to Pen Location. Seabirds attracted to sea cages from colonies at Houtman Abrolhos, resulting in changes to foraging behaviour,	Likelihood Likely (4) Consequence Moderate (2) Hazard Score	***Consequence: Moderate*** *Change to population impacted or potential change in ecosystem structure through increase in the size of breeding populations of increaser species (gulls or cormorants) resulting in kleptoparasitism*	Likelihood Possible (3) Consequence Moderate (2) Hazard Score	***Consequence: Moderate*** *Locations of sites are within range of all seabird populations. Choice of sites is unlikely to reduce this interaction.*

reproductive performance or mortality (see also 2 above)	(8) Risk Level (2) **Moderate**	*or predation.* ***Likelihood: Likely*** *Certain that without management measures gulls and cormorants will exploit fish fee and respond with increase in breeding populations.*	(6) Risk Level (2) **Moderate**	***Likelihood: Possible*** *Occasional interactions may occur even with best practices.* ***Management Controls:*** • *Appropriate bird netting and maintenance including net tension may reduce attractiveness of site to some species.* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring to see if non-increaser species are attracted to sea cages.*
4. FAD effects. Attraction of baitfish, crustaceans and predatory fishes due to FAD effects of superstructures. May result in changes to seabird's natural foraging behaviour.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Change to population impacted or potential change in ecosystem structure through increase in the size of breeding populations of terns or cormorants or other seabird species.* ***Likelihood: Likely*** *Certain that without management measures baitfish will aggregate around sea cages and seabirds will exploit this resource.*	Likelihood Possible (3) Consequence Moderate (2) Hazard Score (6) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Maximum level of change acceptable, will impact some seabird populations positively, i.e. some tern species and pied cormorants.* ***Likelihood: Possible*** *Will occur even with best practices.* ***Management Controls:*** • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring to see if non-increaser species are attracted to sea cages and feed on baitfish schools.* • *Monitoring of gull and cormorant colonies annually to*

				assess populations if feeding observed at sites.
5. Habitat exclusion. Loss of foraging habitat to seabirds due to surface area of sea cages.	Likelihood Likely (3) Consequence Moderate (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Measureable loss of habitat to foraging seabirds minimal.* ***Likelihood: Possible*** *Loss of habitat is likely to occur at a low level.*	Likelihood Likely (3) Consequence Moderate (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Measureable loss of habitat to foraging seabirds minimal.* ***Likelihood: Possible*** *Loss of habitat is likely to occur at a low level.*
6. Lighting management. Disorientation, collision and death of seabirds transiting through site at night due to inappropriate navigation or vessel lighting levels. Lighting may increase zooplankton and provide nocturnal feeding opportunities for diurnal foragers.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Impact to population of shearwaters or storm petrels may be at upper limit, EPBC species likely to be injured or die.* ***Likelihood: Likely*** *Certain that without management measures nocturnal seabirds will collide with structures or vessels. Silver Gulls will forage at night.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.* ***Management Controls**:* • *Prepare Lighting management plan* • *Design of orientation, wavelength and use of lighting* • *Minimise requirements to operate at night* • *Remove need for vessels in area*

				at night. • *Adopt seasonal lighting plan to reduce impacts.*
7. Marine Debris. Ingestion or entanglement of foreign objects such as plastics, netting and other waste from farm activities, causing death.	Likelihood Likely (4) Consequence Minor (1) Hazard Score (4) Risk Level (1) **Low**	***Consequence: Minor*** *Few individuals directly impacted in each year, however shearwaters or other seabird species may be injured or die.* ***Likelihood: Likely*** *Certain that without management measures seabirds will either ingest waste or become entangled in netting.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.* ***Management Controls**:* • *Prepare Waste management plan, including nil overside policy.* • *Maintain regular maintenance of farm infrastructure.* • *Screen vessel scuppers to prevent loss of material overside.* • *Return all wastes including food scraps to mainland for disposal.*
9. Roosting. Seabirds using farm infrastructure as roosting sites, resulting in fouling of infrastructure, reduction in water quality from faecal matter, risk of collision or entanglement and	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8)	***Consequence: Moderate*** *Potential positive impact to increaser species (gulls and cormorants) as well as Bridled Terns.* ***Likelihood: Likely*** *Certain that without management measures seabirds will utilize sea cages or vessels as roosting sites.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3)	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.*

negative staff interactions with fauna.	Risk Level (2) **Moderate**		Risk Level (1) **Low**	***Management Controls***: • *Appropriate bird netting covering entire sea cage, and maintenance including net tension.* • *Design of railings, floats, net rings to reduce roosting sites.* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring to see if increaser species are roosting on sea cages.* • *Use of visual bird deterrents (model hawks/owls).*
10. Seabird Predators. Attraction of aerial snatch predators (Osprey/ White Bellied Sea Eagle) to uncovered sea cages.	Likelihood Possible (3) Consequence Moderate (2) Hazard Score (6) Risk Level (1) **Low**	***Consequence: Moderate*** *Maximum level of impact acceptable due to potential loss of Osprey or sea eagles through entanglement.* ***Likelihood: Possible*** *This may occur with uncovered cages.*	Likelihood Unlikely (2) Consequence Minor (1) Hazard Score (2) Risk Level (0) **Negligible**	***Consequence: Minor*** *Few if any individuals impacted in most years.* ***Likelihood: Unlikely*** *Not expected to occur, especially with bird mesh.* ***Management Controls***: • *Appropriate bird netting and maintenance including net tension* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions above surface around cages i.e. Camera Trap monitoring.*

12. Oil Slicks Created by stock feed and dead fish may increase attract ion of site to olfactory seabirds such as shearwaters and storm petrels increasing risk of entanglement in netting.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate.*** *More than a few individuals impacted particularly EPBC protected diving species (Shearwaters) as well as Pied Cormorants* ***Likelihood: Likely.*** *Certain that without management measures EPBC protected seabirds will be attracted to sea cages and may become entangled.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur in some circumstances within the time frame.* ***Management Controls:*** • *Fish fed pelletized food* • *Feed rate controlled to reduce feed waste* • *Dead fish removed from nets* • *Appropriate bird netting (6cm) and maintenance including correct net tension* • *Appropriate anti-predator netting mesh size and spacing.* • *Appropriate mesh size (6cm).* • *Digital Camera monitoring of interactions i.e. uBRUV and Camera Trap monitoring.*
13. Moored Vessels. Location of accommodation vessel at sites Increase in collision hazard to seabirds, provide roosts, vessel traffic may deter foraging.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8)	***Consequence: Moderate*** *Impact to population of shearwaters or storm petrels may be at upper limit, EPBC species likely to be injured or die from collision.* ***Likelihood: Likely*** *Certain that without management*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3)	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special*

	Risk Level (2) **Moderate**	*measures nocturnal seabirds and some tern or Noddy species will collide with structures or vessel when commuting to from colonies.*	Risk Level (1) **Low**	*circumstances.* ***Management Controls**:* • *Moor vessel near inhabited islands away from site (flight path) and colonies.* • *Prepare Lighting management plan (see above)* • *Minimise requirements to operate vessels at night* • *Reduce lines and rigging on vessels* • *Train staff in appropriate bird handling and reporting.*
14. De fouling operations. Gulls may exploit marine invertebrates from cleaning operations, resulting in food subsidization.	Likelihood Likely (4) Consequence Moderate (2) Hazard Score (8) Risk Level (2) **Moderate**	***Consequence: Moderate*** *Potential positive impact to increaser species (gulls) through food supplementation (see 2 above).* ***Likelihood: Likely*** *Certain that without management measures gulls will feed on waste from de fouling operations.*	Likelihood Possible (3) Consequence Minor (1) Hazard Score (3) Risk Level (1) **Low**	***Consequence: Minor*** *Minor changes to ecosystem structure, few individuals impacted in most years.* ***Likelihood: Possible*** *May occur under special circumstances.* ***Management Controls**:* • *Adopt de-fouling protocols to reduce waste providing food.* • *Dispose of waste away from farm site* • *Digital Camera monitoring of interactions above surface during de fouling operations i.e. Camera*

				Trap monitoring.
6. Disturbance Disturbance to seabirds or colonies from farm site activities, increased activity at Houtman Abrolhos, including vessel operations.	Likelihood Likely (4) Consequence Minor (1) Hazard Score (4) Risk Level (2) **Low**	***Consequence: Minor*** ***Potential impact to some seabirds through increased operational and potential recreational activities by staff.*** ***Likelihood: Likely*** *Certain that without management guidelines increased human activity, particularly recreational may impact seabird colonies.*	Likelihood Unlikely (2) Consequence Minor (1) Hazard Score (2) Risk Level (0) **Negligible**	***Consequence: Minor*** *Few if any individuals impacted in most years.* ***Likelihood: Unlikely*** *Not expected to occur, especially with management of activities.* ***Management Controls**:* • *Adopt management plan to reduce impacts from farm activities, including access to areas adjacent active seabird colonies.* • *Restrict or limit recreational activities, including use of vessels, to those away from seabird colonies.* .

5 Proposed Mitigation Measures

5.1 Risk and Mitigation recommendations

5.1.2 Residual or Untreated Risks

The Department's ' Representation of Aquaculture Operations' outlines the regulators expectations with respect to sea cage design and operation within the Mid-West Aquaculture Zone. This document outlines the best practice tools now used to reduce adverse wildlife interactions including pen construction materials, predator nets, bird nets, barriers, and appropriate feeds and food delivery systems. The use of hormones and antibiotics in fish feed should be limited and regulated by the DoF to reduce the risk of seabirds ingesting treated fish feed.

The residual risks, assuming the effective implementation of those measures, would appear to be FAD effects, lighting and some lateral drift of fish feed outside the seacages.

Mitigation measures are not available for the FAD effects. Should monitoring indicate that prey resources have materially increased for any seabird population then Level 2 monitoring should be implemented (see Section 6). Shifting the pen locations within the Zone may provide temporary relief.

Lights shining on the water-surface enhance the FAD effect by attracting and concentrating plankton and other marine life. This has been a major cause of increasing Silver Gull numbers in the offshore oil and gas industry as the birds feed at night on the resulting prey aggregations. Some wavelengths (e.g. yellow or red light) may reduce the attraction to phototrophic organisms.

Bright lights directed towards the horizon will draw in and disorientate seabirds that make landfall at their colonies at night including shearwaters, storm-petrels and pelagic terns. Fledging Shearwater chicks orientate to lights on the horizon and are common casualties at coastal towns, on ships, fishing boats and even on freeways. The use of bright spotlights or deck lights should be avoided or only operated when they are needed to conduct an operation.

The 'Representation of Aquaculture Operations' indicates that perhaps 1% of feed will be transported outside the pens through the mesh in the lower part of the water column. This feed may aggregate wild fish in the size ranges attractive to foraging Pied Cormorants (i.e. 15-25cm, Sullivan et al. 2006). Cormorants are known to be opportunistic foragers and may take advantage of aggregated prey (Bostrom 2012). If the suggested unbaited underwater video monitoring (see Section 6) indicates the Pied Cormorants are being subsidized in this way then Level 2 monitoring should be implemented. Should feed drift be attracting cormorants to prey aggregations further steps will need to be taken to ensure pellet material (including oils) do not escape from the pens.

6 Monitoring seabird interactions with sea-cage aquaculture

6.1 Monitoring framework

The objective of aquaculture businesses is to sustainably produce marketable fish products by means that are economically profitable.

The objective of the Abrolhos Islands natural resource managers is to ensure that no activities within the Abrolhos Islands Ministerial Reserve cause ecological or social changes that have a negative impact on its other values.

A risk-mitigation framework was presented in Table 4.1 in Section 4 that matched the risk of adverse seabird interactions with sea-cage aquaculture with a variety of previously employed mitigation methods. If implemented these may increase logistical difficulties in fish production and result in additional operating costs. If these measures are not implemented, or are poorly implemented, this may increase the ecological risk. The intensity and scale of monitoring should depend on how each risk is treated or left untreated.

It is proposed that three levels of seabird monitoring be identified and implemented when necessary.

6.1.1 Level 1 - Seabird interactions at the sea-cages

This involves structured observation by the operators to determine if seabirds are being attracted to the pens, whether they are gaining access to supplementary food resources and whether any structures, lights may be causing seabird mortality.

Operators should be required to:

1. Report all seabird mortalities within or immediately adjacent to the aquaculture area (supported by digital photos of the situation) to the Department of Fisheries. DoF should also inform the Department of Parks & Wildlife of significant incidents or issues involving threatened species (Lesser Noddy, Fairy Tern, Australian Sea-lion, and White-pointer Shark etc.).

2. Unbaited Remote (Digital) Underwater Video cameras (uBRUV) should be operated from the seabed and orientated towards the cage mesh during fish-feeding. Interactions with wild fish and protected species should be recorded on the underwater video cameras should be reported for one hour before, during and one-hour after fish feeding. uBRUVs should be rotated around all installed sea cages with each sea cage sampled once a month.

3. Digital Motion Detector Cameras (e.g. Spypoint BF10) with time-lapse capabilities should be deployed on poles with coverage of the surface areas of the sea cages. Periodic time-lapse imagery (daylight= colour, night = IR) should be programmed to monitor for seabird activity on sea cage infrastructure. The cameras will record interaction with seabirds such as roosting (diurnal/nocturnal), foraging (day/night) or hovering over cages.

6.1.2 Level 2 monitoring

The next level of monitoring would be required if repeated interactions are recorded at the sea-cages. If these relate to food subsidization (that isn't to be immediately mitigated) then annual monitoring of seabird tissues (e.g. stable isotope analysis) or seabird diets (pellets / regurgitations) should be required to determine if the energy flow to the seabird population is material and likely to force changes in colony distribution or population size.

If the interactions involve entrapment / entanglement or collisions the seabird mortality should be documented, reported (as for Level 1) and the seabird behaviour will need to be investigated to determine the causal factors.

6.1.3 Level 3 monitoring

If either seabird incidental mortality or food subsidization is significant, and continues to be incompletely mitigated, then it will be necessary to monitor changes in breeding population-size of the interacting (and potentially associated) seabird species. The methodology for components of colony monitoring is outlined in Section 2.

6.2 Monitoring framework methodology

Depending upon the levels of interactions between seabirds and sea cages, monitoring may vary from operator based to intensive independently monitored seabird populations.

We have recommended a performance driven 3 tiered approach to monitoring the likely potential impacts to seabirds. In the first instance, the majority of monitoring may be undertaken using remote digital technology, installed by scientists and operated and maintained by the operators after training. As outlined above, this will involve unbaited Remote Underwater Videos (uBRUV), motion-detector cameras and seabird interaction reporting sheets. The data collected will be heavily reliant upon operators maintaining protocols and reporting honestly and regularly. Although footage from both the uBRUVs and cameras should be retained for examination by DoF inspectors.

We believe the current report, as well as previous data collected by Halfmoon Biosciences, will suffice as a baseline for Stable Isotope levels and existing size and activity patterns of the three key increaser species (i.e. Silver Gull, Pacific Gull and Pied Cormorant). However, depending upon the timing of operations, monitoring of key nesting sites on an adhoc basis will be necessary to ensure that current population levels are consistent. The current low breeding numbers of both gull species is a response to the removal of rock-lobster fishing bait from the system – if for example Silver Gull numbers increase significantly in the interim period prior to sea cages being deployed, and adhoc counts of nests and nest status are not undertaken, then operators will invariably be held responsible for the gull increase.

Currently Halfmoon monitors several seabird populations across the Houtman Abrolhos. It would be feasible to undertake a one-day survey of key SG/PG sites in the Pelsaert Group (these being Post Office Island. Newman Island and Pelsaert Island) to plot and assess breeding status during Halfmoon larger surveys, thereby reducing operator costs.

6.3 Summary of recommended monitoring proposed

The below is a prioritised list of monitoring techniques that meet the DoF guidelines of best practice as well as being practicable, cost effective and time efficient for operators.

Level 1: Surveillance of seabird interactions with sea-cages

1a - Mandatory reporting of all interactions causing seabird entanglement, injury of mortality as described in section 6.1.1.

1b - Sub-surface monitoring of underwater interactions using uBRUVs as described in section 6.1.1.

1c - Above pen surface monitoring of seabird interaction using motion detector cameras as described in 6.1.1.

Level 2: Monitoring for onset of material food/energy subsidisation

2a - Repeat dietary sampling for three increaser species or add species if there is an unpredicted foraging interaction.

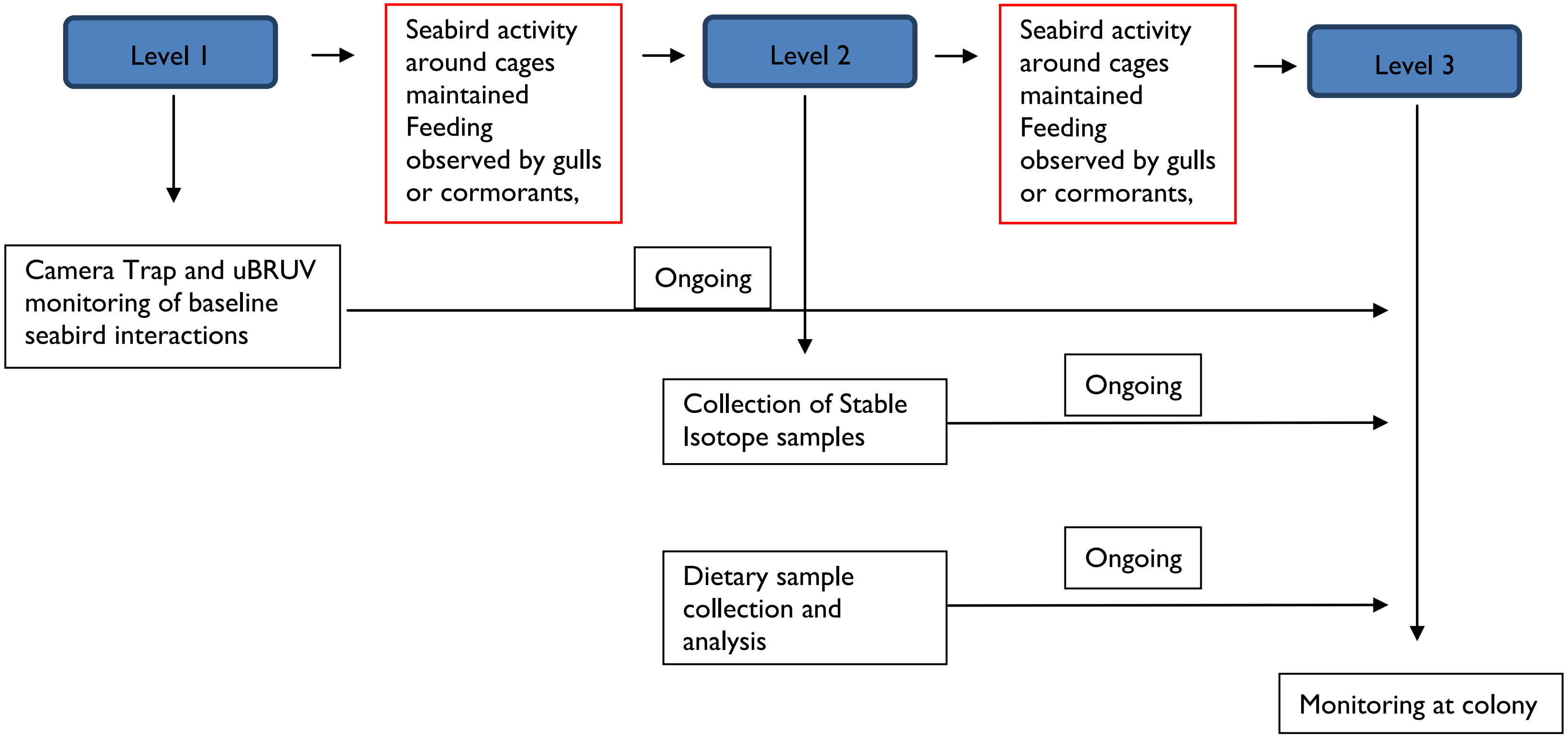
2b - Repeat stable isotope analysis for three increaser species.

Level 3: Monitoring for changes in seabird population size should a significant energy flow from the aquaculture zone be detected by Level 2 monitoring.

3.1 Census and mapping of colonies of the affected species on islands in the Easter and Pelsaert Groups.

3.2 Institute island habitat monitoring (e.g. guano addition, mangroves, colony vegetation) in the event of measured increases in subsidized seabird species from 3.1.

Figure 6.1: Flow diagram illustrating the three tiered approach to monitoring seabird interactions.



7 Conclusion

Several other studies on the potential impacts upon seabirds from aquaculture have identified similar risk factors to those discussed in this document. These include entanglement, habitat exclusion, disturbance from farm activities, increased prey availability through FAD affects, creation of roost sites, changes to foraging success and spread of pathogens (see Sagar 2008, 2013, Lloyd 2003, Comeau *et al*. 2009).

This study shows that additional potential risks associated with aquaculture are the disruption to usual foraging patterns, decline in nesting habitat to vulnerable species through the increase in Pied Cormorant numbers and importantly changes in foraging behaviour and consequent predicted population changes in increaser gull species.

While the potential for populations of the three increaser species (Pied Cormorants, Silver Gulls and Pacific Gulls) to increase through exploitation of food sources associated with sea cage aquaculture are real, we believe that best practices in the structure of sea cages, size and management of netting and protocols of reducing feed waste are likely to reduce the potential for exploitation by these increaser species.

The baseline survey of the distribution of Silver Gulls shows a decline in numbers and the collapse of the autumn breeding period that was almost certainly subsidized by fishery discards and food-waste from the former March - June Zone A rock-lobster fishing season. This rapid response to a change in food availability illustrates the way food subsidization from sea cage aquaculture operations could enhance gull populations with a range of ecological consequences.

The Pacific Gull population has also declined since the last census and this may also be attributable to the reduction of fishing activity at the Abrolhos. No trend is evident in Pied Cormorant numbers.

The baseline investigations on the foraging ecology of the three potentially 'high risk' increaser species indicate that all are currently reliant on naturally available prey types, with littoral zone invertebrates dominating the gull diets and benthic fishes that of Pied Cormorants.

The stable isotope analysis supported the dietary analysis indicating the importance of littoral (benthic and detrital producer) habitats for all three species. The two gulls both showed relationships with the terrestrial food-chains on the islands with Silver Gulls making use of natural berry crops during the food-limited autumn period and Pacific Gulls also functioning as terrestrial predators (probably on other smaller seabirds). This illustrated the potential for changes in gull numbers to alter island ecosystems.

The analysis of seabird movements and foraging behaviour identified a range of potential interactions with fish-farming operations. It was considered that most of these could be mitigated if the management expectations outlined by the Department of Fisheries were effectively implemented from the outset. Three residual risks related to FAD effects, lighting and the lateral drift of feed are identified and possible mitigation measures suggested.

A monitoring framework based on three, performance-based, risk levels has been proposed.

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Appendix 1: δ15N and δ13C Stable Isotope Values (in parts per thousand °/₀₀) for predator and prey tissues collected from the Easter and Pelsaert Groups of the Houtman Abrolhos in 2014.

Field No.	Sample	Predator	δ13C	δ15N
CE1	Feather, Pied Cormorant, Easter Group		-10.8	10.8
CE2	Feather, Pied Cormorant, Easter Group		-9.9	10.6
CE3	Feather, Pied Cormorant, Easter Group		-13.0	13.4
CE4	Feather, Pied Cormorant, Easter Group		-17.9	14.0
CE5	Feather, Pied Cormorant, Easter Group		-18.8	13.8
CE6	Feather, Pied Cormorant, Easter Group		-19.7	12.9
CE7	Feather, Pied Cormorant, Easter Group		-12.2	10.8
CE8	Feather, Pied Cormorant, Easter Group		-16.1	13.2
CE9	Feather, Pied Cormorant, Easter Group		-17.0	12.9
CE10	Feather, Pied Cormorant, Easter Group		-13.4	13.5
PP1	Topshell - *Tectus sp*	Pacific Gull	-11.6	4.8
PP2	Topshell - *Tectus sp*	Pacific Gull	-11.6	5.4
PP3	Topshell - *Tectus sp*	Pacific Gull	-10.2	4.2
PP4	Topshell - *Tectus sp*	Pacific Gull	-10.9	4.3
PP5	Topshell - *Tectus sp*	Pacific Gull	-11.2	4.8
PP6	Topshell - *Tectus sp*	Pacific Gull	-10.3	4.4
PP7	Squid, beaks and mantle	Pacific Gull	-13.0	6.4
PP8	Squid, beaks and mantle	Pacific Gull	-12.0	6.6
PP9	Squid, beaks and mantle	Pacific Gull	-9.8	5.9
PP10	Squid, beaks and mantle	Pacific Gull	-11.2	6.0
PP11	Squid, beaks and mantle	Pacific Gull	-12.0	5.7
PP12	Squid, beaks and mantle	Pacific Gull	-11.8	7.0
PP13	Squid, beaks and mantle	Pacific Gull	-12.4	7.0
PP14	Squid, beaks and mantle	Pacific Gull	-12.3	6.6
SE1	Feather, Silver Gull, Easter Group		-16.7	13.0

SE2	Feather, Silver Gull, Easter Group		-14.0	12.7
SE3	Feather, Silver Gull, Easter Group		-18.2	13.2
SE4	Feather, Silver Gull, Easter Group		-11.7	17.3
SE5	Feather, Silver Gull, Easter Group		-10.6	17.4
SE6	Feather, Silver Gull, Easter Group		-10.1	15.0
SE7a	Feather, Silver Gull, Easter Group		-13.7	13.6
SE7b	Feather, Silver Gull, Easter Group		-14.7	13.5
SE8	Feather, Silver Gull, Easter Group		-12.3	15.1
SE9	Feather, Silver Gull, Easter Group		-12.8	13.0
CE11	Fish scales, Easter Group	Pied Cormorant	-16.0	11.2
CE12	Fish scales, Easter Group	Pied Cormorant	-15.3	11.7
CE13	Fish scales, Easter Group	Pied Cormorant	-12.1	8.4
CE14	Fish scales, Easter Group	Pied Cormorant	-12.0	9.5
CE15	Fish scales, Easter Group	Pied Cormorant	-12.7	8.8
CE16	Fish scales, Easter Group	Pied Cormorant	-10.9	11.3
PP15	Chick feathers, Pacific Gull, Pelsaert Group		-12.6	14.7
PP16	Chick feathers, Pacific Gull, Pelsaert Group		-10.2	13.0
PP17	Chick feathers, Pacific Gull, Pelsaert Group		-12.2	13.8
PP18	Chick feathers, Pacific Gull, Pelsaert Group		-11.3	14.2
PP19	Chick feathers, Pacific Gull, Pelsaert Group		-12.0	14.8
PP20	Chick feathers, Pacific Gull, Pelsaert Group		-10.7	13.8
PP21	Chick feathers, Pacific Gull, Pelsaert Group		-11.2	14.1
PP22	Chick feathers, Pacific Gull, Pelsaert Group		-12.0	13.3

PP23	Chick feathers, Pacific Gull, Pelsaert Group		-12.4	13.9
PP24	Chick feathers, Pacific Gull, Pelsaert Group		-11.6	14.6
CP1	Feathers, Pied Cormorant, Pelsaert Group		-10.3	12.3
CP2	Feathers, Pied Cormorant, Pelsaert Group		-10.4	11.5
CP3	Feathers, Pied Cormorant, Pelsaert Group		-11.3	11.3
CP4	Feathers, Pied Cormorant, Pelsaert Group		-10.4	12.4
CP5	Feathers, Pied Cormorant, Pelsaert Group		-16.1	12.5
CP6	Feathers, Pied Cormorant, Pelsaert Group		-15.8	12.8
CP7	Feathers, Pied Cormorant, Pelsaert Group		-12.1	12.3
CP8	Feathers, Pied Cormorant, Pelsaert Group		-10.7	11.8
CP9	Feathers, Pied Cormorant, Pelsaert Group		-10.1	12.1
CP10	Feathers, Pied Cormorant, Pelsaert Group		-9.6	10.7
SP1	Mantis shrimp carapace	Silver Gull-Pelsaert	-11.8	4.6
SP2	Mantis shrimp carapace	Silver Gull-Pelsaert	-11.8	4.9
SP4	Mantis shrimp carapace	Silver Gull-Pelsaert	-13.6	4.4
SP5	Mantis shrimp carapace	Silver Gull-Pelsaert	-11.9	4.3
SP6	Mantis shrimp carapace	Silver Gull-Pelsaert	-13.5	4.4
SP7	Crab, *Leptograpsus* carapace	Silver Gull-Pelsaert	-12.7	8.4
CP11	Fish scales	Pied Cormorant-Pelsaert	-9.2	7.7
CP12	Fish scales	Pied Cormorant-Pelsaert	-10.6	10.6

CP13	Fish scales	Pied Cormorant-Pelsaert	-9.3	7.8
CP14	Fish scales	Pied Cormorant-Pelsaert	-9.4	7.6
CP15	Fish scales	Pied Cormorant-Pelsaert	-11.4	8.7
SE10	Feathers, Silver Gull, Easter Group		-14.8	13.9
SE11	Feathers, Silver Gull, Easter Group		-15.8	13.2
SE12	Feathers, Silver Gull, Easter Group		-17.1	13.7
SE13	Feathers, Silver Gull, Easter Group		-14.2	16.7
SE14	Feathers, Silver Gull, Easter Group		-14.3	14.6
SP8	Feathers, Silver Gull, Pelsaert Group		-17.9	13.2
SP9	Feathers, Silver Gull, Pelsaert Group		-19.9	11.5
SP10	Feathers, Silver Gull, Pelsaert Group		-17.0	14.1
SP11	Feathers, Silver Gull, Pelsaert Group		-18.1	13.0
SP12a	Feathers, Silver Gull, Pelsaert Group		-18.6	12.3
SP12b	Feathers, Silver Gull, Pelsaert Group		-17.1	13.6
SP13	Feathers, Silver Gull, Pelsaert Group		-17.0	13.4
SP14	Feathers, Silver Gull, Pelsaert Group		-20.6	12.2
SP15	Feathers, Silver Gull, Pelsaert Group		-19.5	12.4
SP16	Feathers, Silver Gull, Pelsaert Group		-10.8	16.0
RBP1	Ant *Polyrachis amoneoides* chitin	live sample	-21.2	23.8
RBP2	Ant *Polyrachis amoneoides* chitin	live sample	-21.2	23.3
RBP3	Ant *Polyrachis amoneoides* chitin	live sample	-20.8	23.6
RBP4	Ant *Polyrachis amoneoides* chitin	live sample	-21.1	23.8
RBP5	Ant *Polyrachis amoneoides* chitin	live sample	-21.2	23.6
NBP1	Ant *Polyrachis amoneoides* chitin	live sample	-17.9	24.4

NBP2	Ant *Polyrachis amoneoides* chitin	live sample	-18.7	24.4
NBP3	Ant *Polyrachis amoneoides* chitin	live sample	-18.4	24.4
NBP4	Ant *Polyrachis amoneoides* chitin	live sample	-19.0	24.4
NBP5	Ant *Polyrachis amoneoides* chitin	live sample	-18.7	24.2