M. Phil. Polar Studies - Thesis:

Remote Sensing of Antarctic Penguin Populations

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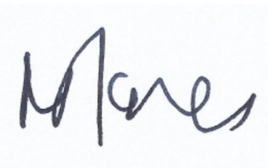
Signature:  **Date:** June 2015

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Abstract

Penguins, high trophic-level predators almost exclusively confined to the Southern Ocean, are believed to be particularly susceptible to the unprecedented climatic changes that are currently being experienced in the region. Indeed, the two species of interest to this research, the chinstrap and gentoo penguins, are designated as 'indicator species' or sentinels of change within the natural environment by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), the responsible international agency for conserving Antarctic marine life. However, despite the intrinsic role that the species play, there is a dearth of knowledge about even basic demographic and biological aspects (census, distribution, habitat requirements, lifecycles) due, in the main, to the significant environmental and logistical barriers that are presented when considering field surveys within the region. As such, the potential of remote sensing applications and aligned software are beginning to be realised and are proving particularly apt at augmenting the data collected from the more traditional methods of ground-surveys and the laborious counting of species manually from imagery.

To test this belief, freely-available '*open-source'* software was used to design and develop research-specific methodological approaches to provide both population census information and to calculate nesting densities from aerial photography taken of the Cape Shirreff rookery, Livingston Island, the South Shetland Islands; with open-source software explicitly chosen in preference to commercial packages to test the potential of and for such software and the approaches described herein to be used by all, regardless of background and experience.

The methodological approaches developed produced very favourable results: for population census, the counts were within 5% of the actual in-situ ground-counts recorded by the US Antarctic Marine Living Resources (US AMLR) programme; whilst nest-to-nest distances and colony density calculations correlated very well with the (admittedly, limited) published data, indicating that the adopted approaches described herein may be reliably utilised for future surveys, albeit with some modifications. Two further, unheralded, revelations emerged: firstly, that nest-to-nest distances of and between the two species increased markedly within congeneric colonies when compared to those colonies where only one species is nesting; whilst, secondly, the colonies are situated within two quite narrow bands within the rookery, leaving a broad swath of ostensibly suitable territory uncolonized. Whilst the reasons are somewhat uncertain, these observations further illustrate the imperative need for a concerted research campaign of appropriate spatio-temporal extent.

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In all works on natural history, we constantly find details of the marvellous adaptation of animals to their food, their habits, and the localities in which they are found.

Alfred Russel Wallace (1853).

1.0 Introduction

1.1 Overview & Context

Penguins - of the taxonomic order, *Sphenisciformes*; family *Spheniscidae*– are generally regarded as being particularly sensitive (and vulnerable) to climate change (*inter alia:* Barbraud & Welmerskirch, 2001; Ainley, 2002; Trivelpiece *et al.,* 2011; Korczak-Abshire *et al.*, 2013; Jenouvrier *et al.*, 2014), particularly when colonies are situated towards the edges of their geographical ranges (Pistorious *et al.*, 2010).

Indeed, such is the vulnerability of the order to climatic perturbations and other factors such as the over-exploitation of prey species, that the Ecosystem Monitoring Program of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), identifies four species of the *Spheniscidae* family as *'indicator species'*[1] of change within the Antarctic marine ecosystem. Further, penguins are also noted as being the dominant force within the Antarctic and Southern Ocean marine food web, comprising circa. four-fifths of the total avian biomass of the sub-Antarctic region alone (*inter alia,* Trathan, 2004; Barber-Meyer *et al.,* 2007; Southwell & Emmerson, 2013).

It is two of the four *Spheniscidae* indicator species, *Pygoscelis antarctica* (chinstrap) and *Pygoscelis papua* (gentoo) penguins, that are of central interest to the research described herein.

1.1.1 Data Deficiencies & Species Understanding

Despite the importance attached to penguins and their integral role within the Antarctic and Southern Ocean biomes, and the significant contemporary threats that exist and future threats that are envisaged, our knowledge of even basic demographic and lifecycle requirements is lacking, be this in terms of population distributions, census information, and lifecycles, or with regard to climatic and environmental requirements or preferences. The absence of such

[1] CCAMLR, the primary Antarctic marine ecosystems governance body established by international convention in 1982 with the "*objective of conserving Antarctic marine life"*, identifies the three *Pygoscelid* species as three of the eight identified indicator species (see chapters 2 & 3). Such indicator species allow for the detection and recording of "*significant changes in critical components of the marine ecosystem…to serve as a basis for the conservation of Antarctic marine living resources" (*Source: CCAMLR website).

knowledge precludes effective management stratagems from being designed whilst also reducing our ability to chart changes in the natural environment through the identification of such variables as population trends over time.

In point of fact, the knowledge of population trends in particular is thought to be critical to the conservation and management of species and ecosystems, providing estimable patterns of abundance over time from which inferences may be made on the wider state of the environment (Baylis *et al.*, 2012). Regular population census are therefore fundamental to conservation efforts (*inter alia*: Turner *et al.*, 2003; McMahon *et al.*, 2014), but matters are generally exacerbated within the polar regions due to the inherent and significant, logistical and environmental challenges that present substantial hurdles when developing research projects (Fretwell *et al.,* 2012). This has (largely) led to conservationists beginning to understand and harness the capabilities of remote sensing technologies as a nature conservation aid, with the contention being here, that improvements in remote sensing capabilities and in our understanding of techniques and applications has allowed for traditional approaches to species monitoring (i.e., costly in-situ ground-counting and laborious manual counting from imagery) to be successfully augmented using freely-available computer software when applied to colonial species such as penguins (*inter alia:* Gillespie *et al.,* 2008; Southwell & Emmerson, 2013; McMahon *et al.,* 2014; Fretwell *et al.,* 2014b).

Further, it is asserted that such remote sensing applications are particularly suitable to the geographically isolated and spatially broad extents of the polar regions, allowing key observations to be made on the current (and proposed) state of the environment and the species that reside therein (*inter alia*: *Kerr* & Ostrovsky, 2003; Trathan, 2004; Barber-Meyer *et al.,* 2007; Lydersen *et al.*, 2007; Gillespie *et al.*, 2008; Platanov e*t al.,* 2013; Fretwell *et al.,* 2014a; McMahon *et al.,* 2014).

1.2 Motivation for Research

The main motivation for the research is to help to address the extant data deficiencies by illustrating that open source image-processing software can be used by an individual from a non-technical background and without prior experience to provide scientifically robust and valid demographic information for colonial species such as penguins, thereby aiding our understanding of the effects of change on species and the ecosystems within which they reside.

1.2.1 Open-Source Software

The digital imagery provided by remote sensing applications is ideal for computer analysis, indeed, as Rees (2013, p.8) states, 'image processing' "*forms an integral part of remote sensing*". Whilst an array of expensive image processing software exists commercially, open-source[2] software offers very similar capabilities and, given that it is available for free to all, provides a very effective means of allowing a much wider audience to develop capabilities and to undertake research, thus helping to foster 'citizen science'. Further, given that such open-source software will typically offer slightly reduced functionality in comparison to commercial software packages, it is contended that the software is far easier for a novice to learn the basic requirements within short timeframes. It therefore also offers far greater usability, whilst the capacity to either personally design project-specific software tools or to use previously created 'plug-ins' provides for ever-evolving functionality.

With the above in mind, and after a great deal of experimentation, ImageJ processing software[3] was chosen as the most appropriate to the research in hand – albeit alternative platforms would have offered comparable capabilities, such as with MATLAB.

ImageJ, originally released in 1997, is a Java-based image processing software platform developed by the US National Department of Health and Human Services. It is a readily extendable platform, utilising 'plug-ins' (see above) to allow the user to custom-build software to incorporate pertinent analysis tools. ImageJ works with 8-bit to 32-bit greyscale and colour images, allowing the operator to display, edit, and analyse images, and can read multiple file formats, such as the widely used GIF (Graphics Interchange Format) and TIFF (Tagged Image File Format) file formats.

In addition to ImageJ, two other open-source packages were extensively used, namely: MultiSpec (for analysing multispectral and hyperspectral imagery) and, QGIS (Quantum GIS), a geographical information system. These are discussed further in chapter 5.

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[2] Open source software is where the original source coding is made available to anyone. It is freely accessible and has given rise to the so-called 'open source movement' or 'Open Source Initiative' (http://opensource.org/)

[3] Specifically, ImageJ version 1.48: http://rsb.info.nih.gov/ij/

1.3 Hypothesis & Research Objectives

1.3.1 Hypothesis

The basic tenet or hypothesis of the research is that *open-source* computer image-processing software applications may be used to 'automatically or autonomously[4]' analyse data and imagery collected from remote sensing platforms, providing results that positively and accurately correlate with those from the more traditional approaches of ground-counting and manual counting from imagery, whilst allowing for very significant savings to be made in terms of time and money given the inherent, pronounced, difficulties in undertaking monitoring surveys in the polar regions.

Whilst for this thesis, the data and imagery provided are from an aerial platform, the recent advent of ultra-high resolution satellite imagery (offering sub-metre resolutions of up to ~ 34cm, and, possibly, to 30cm), means that the approaches described herein may be equally applicable to satellite remote sensing data in the very near future.

1.3.2 Research Objectives

In order to attempt to prove the hypothesis, the thesis has two over-riding research objectives, which are hierarchical in nature:

- the *first objective* is to test and assess the potential for remotely sensed imagery and open-source image processing techniques to provide accurate counts of the total number of nests within a penguin colony (which I refer to as the '**population census**' approach), when compared to the results from data collected from in-situ ground-surveys and from manually counting nests from digital imagery; with nests here being an accepted proxy for the number of breeding individuals within a colony (with one nest equating to one breeding pair of penguins); whilst,
- the *second objective,* '**area-density**', relates to two investigations: firstly, to determine whether accurate nest-to-nest distances can be established for the species utilising the results from the population census studies (above); and, secondly, to establish whether

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[4] 'Automated' to a varying degree. Limited research has been undertaken to date on this area, however, such practices are typically defined as being either '*automated*' or '*semi-automated*' dependent on the degree of operator involvement required, but the terms are somewhat of a misnomer as expanded on later within the thesis.

accurate density figures (i.e. the number of nests per m^2) can be established based on census and area information and the species distribution patterns determined within the first investigation.

1.4 Terminology

The literature is somewhat inconsistent with regards to the definition of a penguin 'rookery' and 'colony'. For clarification, the following definitions have been adopted here:

- '*Rookery*': the full assembly of birds in a particular location; i.e. Cape Shirreff in its entirety is deemed to be the rookery; and,
- '*Colony'* the discrete group of nesting birds or nests to be found within a rookery; i.e. for the purposes of this research, the colonies are those defined areas of nests found within the Cape Shirreff rookery. (Source: adapted from Stonehouse, 1975).

Further, Stonehouse notes that '*sub-colonies*' may also be determined and refer to outlying individuals located a discrete distance from the main colony. However, the classification is not as helpful here, for the colonies within the study area (Livingston Island) are generally limited in size compared to elsewhere within the South Shetland Islands archipelago and wider region (notably, South Georgia and the South Sandwich Islands), and, as agreed with BAS representatives at a meeting on the 8th of April, 2015, all populations identified from the aerial imagery are referred to here as 'colonies' irrespective of whether they are limited to a few individual nests and/or appear to be located in separation from the main assemblages.

In a similar vein, the results do not allow for the identification of non-breeding individuals which are typically positioned some distance (metres) from the main colonial area. All nests identified are taken to be representative of current breeding pairs given that the aerial photography was deliberately taken in the month of December as this is the period during the annual lifecycle of both species when one of the breeding pair will always be on/near the nest. For chinstrap penguins, this coincides with either a period of settlement on the nest or of egg-laying; and for gentoos, chick-rearing or the beginning of fledging (Borboroglu & Boersma, 2013). Thus for nests identified within the imagery, the vast majority have one of a pair of breeding penguins in residence - with one nest therefore representative of a breeding pair of penguins, such that fifty nests, for example, equates to fifty breeding pairs or one hundred individual penguins - excluding chicks which due to the high (but highly variable) mortality rates are not thought to be reliable indicators of demographic change.

Lastly, whilst the genus of interest to this research, the brush-tailed penguins or *Pygoscelids* comprises three species – namely, the Adélie (*Pygoscelis adeliae*), chinstrap (*Pygoscelis antarctica*) and gentoo (*Pygoscelis papua*) penguins – it is only the chinstrap and gentoo species that are present at Cape Shirreff. Therefore, the term '*Pygoscelid/s'* is taken to refer to either/both of the chinstrap and gentoo penguin species and not to the Adélie penguin unless otherwise stated. For brevity, the text refers in the main to the English names of species (for example, 'chinstrap' and/or 'gentoo'), rather than the Latin binomial nomenclature (e.g. '*Pygoscelis antarctica'* and/or '*P. papua*') unless otherwise appropriate.

1.5 Thesis Structure

The second chapter of the thesis proceeds to describe the salient characteristics of the Antarctic biome, the historical and contemporary threats to penguins, including the influences of regional climate change and ocean-atmospheric phenomena; together with introducing the theme of remote sensing, both in terms of its emerging importance for nature conservation management in general, and with regards to penguins in particular.

Chapters three and four are designed to familiarise the reader with the genus (*Pygoscelis*) and species (*Pygoscelis antarctica* and *Pygoscelis papua*) of interest, and to the research locations (at Cape Shirreff, Livingston Island, the South Shetland Islands), respectively. Chapter five is concerned with a description of the design of the methodologies and their development; with chapters six and seven cataloguing and analysing the results that were generated from the investigations that were undertaken in lieu of the first and second research objectives, respectively. The concluding chapter (eight) provides a synthesis of the key themes and points elucidated from the research including the identification of any key recommendations such as in respect of future research requirements. A comprehensive bibliography may be found immediately after the concluding chapter, and preceding the appendices, of which there are twelve in all, beginning with a full list of the acronyms and abbreviations used within the report and their definitions/usage; whilst the latter appendices provide for evidence of additional outputs from the experiments described within the main body of the thesis. Whilst not essential, theses appendices should be viewed in conjunction with the relevant chapters and as notified within the text where pertinent.

2.0 Penguins: Threats & the Importance of Remote Sensing

2.1 Antarctic Biogeography: Contextual Note

For contextual reasons, it is pertinent to precede discussions, here, and consider that Antarctic species have adapted and evolved to life in increasingly extreme conditions over the last 100 million years or so. As a consequence, quasi-distinct Antarctic biogeographical regions have established over time which, in turn, have led to the evolution of geographically-restricted taxonomic groups displaying distinct "*patterns of species distribution and endemism*" (Rogers *et al.*, 2007b, p.2,187). Of the three Antarctic biogeographical regions identified, namely, the 'continental Antarctic zone', the 'sub-Antarctic zone', and the 'maritime Antarctic zone' (Bergstrom e*t al*., 2006), it is the latter within which the South Shetland Islands are situated.

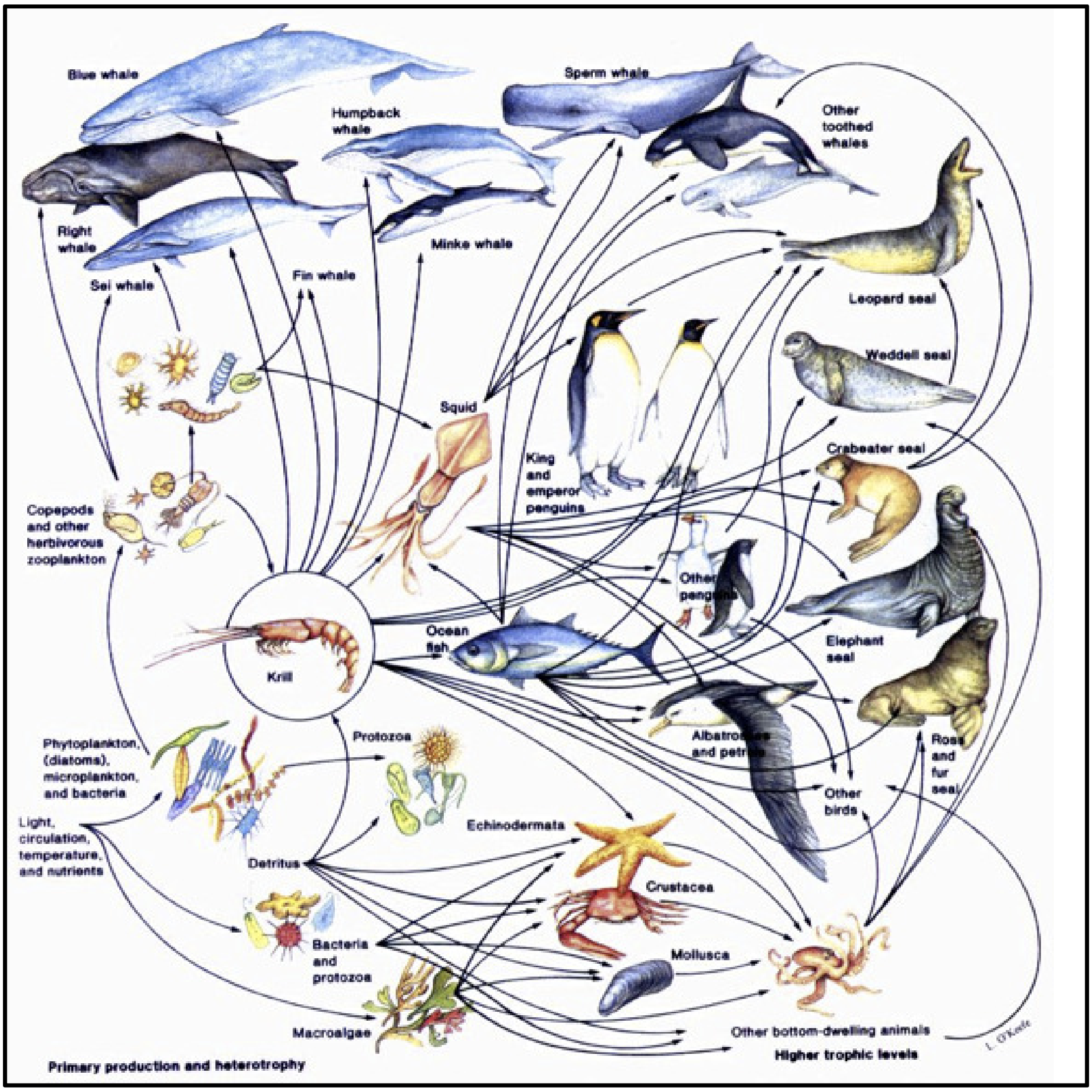
A representation of the chief biological components of the Antarctic food web are depicted within figure 2-1. Whilst necessarily stylised and oversimplified in terms of being limited to portraying example species, only, the figure provides for the key trophic levels within the biome, with primary producers, phytoplankton and zooplankton, at the bottom, whilst illustrating the position of the top predators at the higher trophic levels, which includes all Antarctic penguins, and the integral role that Antarctic krill (*Euphausia superba*) plays as the dominant food source within the ecosystem. Modifications to the structure of this food web are either 'top-down' effects, for example, the overriding effect that the onset – and then cessation – of whaling had between the 18th and 19th centuries, or 'bottom-up' effects, such as the pronounced effects on the patterns of sea ice algae production (primary production) caused by increasing variability in sea ice coverage.

2.1.1 Adaptation

The adaptation of species in response to environmental and climatic conditions, from the altering of physiologies, to the modification of lifecycle traits, is an important consideration when attempting to determine the consequences for such species of climatic and environmental perturbations, i.e. that endemic polar species are often more vulnerable to change, and less able to modify their lifecycles in response to changing conditions, than those from more temperate regions. However, this is not always the case, with some species displaying quite pronounced 'phenotypic plasticity[5]' that enables rapid (evolutionarily-speaking) modification of lifecycles and distributions, with phenotypic plasticity thought to be especially important for long-lived species (Lescroel *et al.*, 2014) such as penguins.

Irrespective, all species are thought to respond in one of three ways to rapid and/or irregular environmental change, namely: (a) they migrate to more favourable habitats; (b) they adapt to cope with the new conditions, or; (c) they become extinct (Clarke *et al.*, 2006).

Figure 2-1 The Antarctic Food Web[6]



[5] The ability of an organism to change its physiological characteristics in response to environmental change.

[6] Source: adapted from Kaiser *et al.* (2011).

Correspondingly, the ecophysiological responsive capabilities of each species, for example in terms of adaptive tolerances to temperature variability, will enhance or diminish their chances for survival (Duarte, 2008[7]).

2.2 Historical & Contemporary Threats

2.2.1 Historical Threats & Demographic Influencers

Historical threats to Antarctic penguin species were in the main confined to natural predation and exploitation by man, for eggs, feathers, and oil, together, ironically, with habitat destruction due to the construction of certain scientific research bases[8].

Whilst it is true to say that the genus as a whole tends to exhibit significant but natural interannual variation in populations (see chapter 3), further aligned factors are also thought to significantly influence the demographics. Chief amongst these would appear to be the availability of prey (Ainley *et al.*, 1995), but closely followed by the availability of suitable habitat, particularly in terms of suitable territory for breeding and nesting.

Commensurate factors include: the influence of the physical and biological settings in general, for example the sea ice environment and food availability, respectively; the degree of adult mortality during the non-breeding season; chick mortality during the breeding season; the sea ice conditions *outside* of the breeding season (and the consequences for the number of birds that arrive to breed)[9]; the duration of sea ice in proximity to breeding sites (which may influence, for example, the start of breeding, the size of the clutch, and the likelihood for breeding success); and, changes in emigration and immigration between colonies and rookeries.

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[7] *"The variation in the values of life history characteristics (age of sexual maturity, fecundity, growth and survival rate) as a response to extreme environments is specific to each species, and it is this variation that determines their demographics and population dynamics, which in turn determine their distribution and abundance. Furthermore, the ecophysiological adaptations of each species (such as tolerance to extreme temperatures)…limit or favour their adaptation to ice and other extreme living conditions"* (Duarte, Ed. Chapter 3, p. 92).

[8] Croxall (1986) recounts the disturbance caused at the joint US-New Zealand research base at Cape Hallett, Ross Sea (1956-1973), during the construction of which between 8,000 and 10,000 Adélie penguins were displaced and prevented from returning, As Croxall notes, the "*population subsequently declined by a further 10,000 pairs*" (p.58).

[9] As Trathan *et al.*, 1996, note "*it is possible that the condition of the regional sea ice in the areas where penguins forage after one breeding season ends and before the next starts, is of major importance for over-winter survival, or for regaining breeding condition"* (p.328).

2.2.2 Contemporary Threats & Regional Climate Change

Threats from both predation (chiefly, from leopard seals but also from orca and skuas) and the effects of man (through tourism and research) remain, but *contemporary* threats are thought mostly associated with commercial fisheries[10] (both direct risks attached to penguins being taken as a by-catch, and indirect when penguins compete for the same prey), and with the general and genus-specific effects of climate change.

Whether through anthropogenic means or not, it is beyond scientific dispute that the last five decades have witnessed marked changes in air temperatures (and, consequently, air moisture content) in parts of Antarctica, with parallel changes in sea surface temperatures (SSTs) (Bergstrom *et al.*, 2006), with the western Antarctic, including the Western Antarctic Peninsula (WAP) and islands of the Scotia Arc, being one of the most rapidly warming regions on earth (Melbourne-Thomas *et al.*, 2013), with Trathan *et al.* (2007), noting "*even small temperature changes can potentially lead to major environmental perturbations"* (p.2,351).

Ostensibly, this has led to the expansion of the ranges of both chinstrap and gentoo penguins. However, such an expansion has not resulted in wholescale increases in the populations of the two species, with breeding populations of chinstrap colonies having declined by approximately 50% in most locations over the same period of time (Hinke, 2012, unpublished), and gentoo penguins showing moderate increases in some locations but reductions at other key colonies.

Indeed, for seabirds, and therefore penguins, and particularly congeneric[11] penguins species, the impacts of climate change are complex and varied (*inter alia*: Ciaputa & Sierakowski, 1999; Lyver *et al.,* 2014), ranging from a decrease in prey availability to an increase in breeding failure and/or chick mortality. Such impacts may also be amplified for long-lived species of generally low physiological adaptability such as the *Pygoscelids* which tend to "*operate at the limits of their tolerance*" (Forcada & Trathan, 2009, p.1,618).

[10] Commercial fisheries within the Southern Ocean are currently permitted to fish for Antarctic krill (*Euphausia superba*), Patagonian toothfish (*Dissostichus eleginoides*), Antarctic toothfish (*Dissostichus mawsoni*), and mackerel icefish (*Champsocephalus gunnari*).

[11] Congeneric: of the same genus (the class/division of organisms).

Whilst the potential impacts of such warming on species in general are numerous, including in terms of magnitude and effects, positive or negative (*inter alia:* Barber-Meyer *et al.*, 2007; Fretwell *et al*. 2011 & 2012; Southwell & Emersen, 2013), it is clear that the alteration in sea ice dynamics, particularly during the winter months, has the potential to have the most direct impact on Antarctic marine fauna. Penguin species may be viewed as being particularly susceptible given their general dependence on Antarctic krill (*Euphausia superba*), a cold water species, with the winter survival of krill larvae dictated by sea ice extent (Clarke *et al.*, 2006; Forcada & Trathan, 2009; Hill *et al*., 2013), and which are generally believed to be negatively affected by sea ice decline and ocean warming (*inter alia*: SCAR, 2014; Trathan & Agnew, 2010).

Other threats associated with climate change are becoming apparent. These include an increase in extreme weather events (Lescroel *et al.,* 2014); an increase in accessibility to, and within the region for, research, tourism, and commercial fishing due to diminishing sea ice, and increased pollution from such activities; an increase or decrease in available, suitable, habitat; the introduction of invasive species to the region; and impacts on such facets as the modification of complex food webs and the availability of food sources, and on breeding success (*inter alia*: Bergstrom *et al.*, 2006; Duarte, 2008; Trathan & Agnew, 2010).

Whilst exact causal mechanisms remain opaque, climatic impacts may be usefully summarised as being most evident in the following:

a) in the changes in the distribution of a species, such as a poleward shift in populations of chinstrap penguins and encroachment on historic Adélie penguin sites; and with the sea ice-intolerant gentoo penguin populations expanding southwards along the Antarctic Peninsula, having moderately increased at 32 of 45 sites investigated between 1979 and 2010, echoing the diminishing of sea ice coverage in the area/s (SCAR, 2014);
b) in the so-called "*match-mismatch*" effect (Trathan & Agnew, 2010, p.290), whereby reproductive timescales are timed to coincide with the maximum availability of prey but that such timescales can be significantly impacted on by ecosystem changes such that some penguin colonies exhibit highly variable recruitment strategies;
c) in the alteration of migration routes between summer and winter foraging groups (particularly applicable to chinstrap penguins but not to the same degree for gentoo penguins given their preference for staying close to breeding sites throughout the year);

d) in changes to phenology, including such factors as a change in breeding, egg laying, and fledging times;[12]
e) in alterations in total population numbers ('census') and population densities, such as in terms of direct or indirect impacts on fecundity; and,
f) in changes in "*community interactions*" (*ibid.* p.291), whereby wholesale rookery and colony changes may occur due to increasing temperatures and sea ice reductions.

Further, Forcada & Trathan (2009) comment that modifications "*in predator-prey interactions, community composition and biogeography are already affecting penguins as a result of climate change*" (p.1,626). Such commentary is borne out by the findings of several important research projects undertaken during the last decade or so and based, variously, on both contemporary and historical (c. early 1970s) records of penguin populations.

In 2006, for example, Clarke e*t al.* refer to the monitoring of Adélie penguins within the WAP and extending for a period of over 30 years, surmising that the sea ice-obligate Adélie penguin had decreased in population due (it was thought) to a corresponding decline in winter sea ice extent; with Forcada *et al*. determining in the same year that climate change had deleteriously affected the availability of suitable habitat for *Pygoscelid* penguin species. In 2011, Trathan *et al*. report on the first recorded loss of an Emperor penguin (*Aptenodytes forsteri*) colony due, at least in part, to a climate-induced reduction in the duration of sea ice; whilst in 2014, Boersma & Rebstock provide evidence of climate change-induced extreme weather events increasing the likelihood and frequency of reproductive failure in Magellanic penguins. Also in 2014, Clucas e*t al.* specifically examined the effects of a changing climate on the *Pygoscelis* genus, concluding that whilst the 'generalist' (in terms of prey and habitat requirements) gentoo penguin is likely to be a climate change "*winner*" (p.1), both Adélie and chinstrap penguins are thought to be "*losers*" due to their more particular requirements (*ibid.).*

However, the uncertainty surrounding the subject is also further compounded by disagreement in some quarters in terms of the magnitude of the effect of the so-called 'krill surplus' theory on historical and contemporary penguin populations. This theory contends that a reduction in the number of baleen-whales and Antarctic fur seals due to exploitation by

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[12] Trathan & Agnew (2010), for example, report that gentoo penguins breeding on South Georgia produced their first egg some ten days earlier than had been the case 18 years beforehand.

man during the 19th and 20th centuries subsequently led to an increase in penguins at that time due to reduced competition for prey; whilst, the recovery of whale and seal populations since that time coupled with reductions in sea ice duration and extent, and the proposed resultant reductions in available krill populations, are thought to be having a deleterious impact on penguin populations today.

The theory remains contentious in some quarters, not least in terms of a failure to fully allow for an analysis of such critical elements as natural interannual population fluctuations, climatic perturbations, and additional climatic forcing elements. The debate does though serve to further highlight our general paucity of knowledge which may only be remedied via the undertaking of continuous, comprehensive, biological and demographic censuses.

2.3 Penguins as Indicators of Change

As noted earlier, the chinstrap and gentoo penguins are designated by the CCAMLR as 'indicators' of significant ecosystem change within the Southern Ocean[13], in part due to their wide geographical distribution within the region, but also in lieu of their high conservation value (Trathan *et al*., 2012), including that penguins comprise c. four-fifths of the entire avian biomass of the region.

A number of variables are thought to dictate the efficacy of an indicator species. For penguins, these include: the geographical distribution of the species, natal philopatry (the return of a species to its birthplace to breed), the foraging behaviour, longevity, and reliance on key prey species (Trathan, 2004).

The CCAMLR Ecosystem Monitoring Program (CEMP) was established to:

- *"detect and record significant changes in critical components of the marine ecosystem within the Convention Area, to serve as a basis for the conservation of Antarctic marine living resources",* and to:

[13] The other indicator species being: the third species of the *Pygoscelid* genus, the Adélie penguin (*Pygoscelis adeliae*), together with the macaroni penguin (*Eudyptes chrysolophus*), black-browed albatross (*Thallasarche melanophrys*), Antarctic petrel (*Thalassoica antarctica),* cape petrel (*Daption capense*), and the Antarctic fur seal *(Arctocephalus gazelle*).

- *"distinguish between changes due to harvesting of commercial species and changes due to environmental variability, both physical and biological*[14]*"*.

Which may be interpreted for our purposes as, in essence, a requirement for population data for penguins so that natural and anthropogenic causes of change can be determined and differentiated to the aid of species conservation.

Thus, the monitoring of such indicator species allows reasonably robust inferences to be made on the health of the Southern Ocean (*inter alia*: Barber-Meyer *et al.,* 2007; McNeill *et al*., 2011; Fretwell *et al*., 2012; Southwell & Emersen, 2013); albeit, Coria *et al.* (2011) caution that the use of seabirds as sentinels of change may not be wholly possible due to "*the complex interactions in Antarctic ecosystems and the potential confounding effects of human impacts"* (p. 207).

2.4 The Role of the Ocean-Atmosphere System

It is salient, here, to briefly highlight the role of the ocean-atmosphere system in terms of regional climate, and climatic and oceanic perturbations and, thus, in terms of the influences of such phenomena on the Southern Ocean and Antarctic ecosystems.

In relation to the marine ecosystem (and, therefore, penguins) three phenomena are particularly noteworthy: the Southern Annular Mode (SAM), the Amundsen Sea Low (ASL), and the El Niño Southern Oscillation (ENSO). Whilst our understanding of the interactions between these most complex of phenomena and their effects on climate and, subsequently, on ecosystems, is incomplete, one aspect that does appear clear is that all three are linked to SST variation within the Southern Ocean and consequently, in part, to the distribution of sea ice within the region (Forcada & Trathan, 2009).

On an interannual to decadal timescale, tropospheric circulation in the region is driven by both the SAM and by the ENSO but there is considerable disagreement on their relative importance. Whilst originating within the Pacific Basin, the ENSO is thought, through teleconnections, to affect global climatic perturbations, including within Antarctica. In essence, it is believed that during a typical ENSO event, the ASL is weaker than normal and

[14] Source: CCAMLR CEMP website: https://www.ccamlr.org/en/science/ccamlr-ecosystem-monitoring-program-cemp

precipitation and temperature anomalies occur, further exacerbating any regional climatic changes and weather patterns that may be occurring and their influence on ecosystem diversity and function. As Trathan *et al.* (2007) note, the short-term changes that arise as a result of an ENSO event "*herald potential long-term changes [to the Southern Ocean ecosystem] that may ensue following regional climate change*" (p.2,351)[15].

Whilst, the SAM, a circumpolar pattern of atmospheric displacement, describes the north-south movement of the westerly wind belt that rings Antarctica and which dominates the middle and higher latitudes of the southern hemisphere. Periodically, the location and intensity of the exchange of air pressure between the mid-latitudes (higher pressure) and the Antarctic region (lower pressure) changes, and over the last 50 years the SAM has become more positive, resulting in stronger westerly winds (by up to 20% according to Turner *et al.*, 2013), and resulting in the poleward migration of westerlies by 1-2^{o} of latitude. Consequently, this intensification and displacement of westerly winds, has led to a deepening of the ASL, with ensuing effects on temperatures and sea ice. Indeed, the ASL may be thought of as a dynamic, fluctuating, low pressure system located in the Pacific sector of the Southern Ocean, the velocity and position of which is "*crucial for understanding regional [climatic] change"*[16].

2.5 The Importance of Remote Sensing for Nature Conservation

Decades of data from satellite remote sensing observations have aided our interpretation and knowledge of mesoscale and regional-scale ocean-atmospheric processes such as the ASL, ENSO, and SAM, together with recording the rise in SSTs linked with global climate perturbations and, indeed, in determining the primary role the oceans play in such climate change (Horning *et al.*, 2010).

In essence, 'remote sensing' may be regarded as "*the collection of information about an object without making physical contact with it"* (Rees, 2013, p. 1). As will become apparent

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[15] Whilst Davis & Renner (2003) comment that "*there is no doubting that El Niño events can have immediate and catastrophic impacts upon penguins. During El Niño events, the sea surface temperature increases, resulting in a band of warm water at the surface that prevents upwelling of nutrient-bearing colder currents. As a consequence, productivity is reduced, which ultimately limits the availability of food to the likes of penguins*" (p.171).

[16] Australian Government, Bureau of Meteorology: http://www.bom.gov.au/climate/enso/history/ln-2010-12/SAM-what.shtml

during the remainder of this thesis, remotely sensed data, be it collected from satellite observations, from the analysis of aerial photography, or from emerging platforms (unmanned aerial vehicles, kites, platforms connected to balloons, etc.), is becoming an integral component of efforts to manage and conserve biodiversity and ecosystems, particularly for remote and hostile environs as found in Antarctica where traditional ground surveying is either not possible from a logistical and climatic perspective or incurs significant costs, temporal and financial. Moreover, remote sensing allows for easily repeatable surveying and at geographic scales that would simply not be possible from in-situ monitoring (*inter alia:* Gillespie *et al.*, 2008; Horning *et al.*, 2010; Herkul *et al.*, 2013; Kerr & Ostrovsky, 2013), thus providing the spatio-temporal dimensions (McMahon *et al.*, 2014) that have to date been largely impossible to achieve in the region and that are of paramount importance when establishing trends in the impacts associated with climate change. As Gould (2000) notes, remote sensing "*provides the best tool...to analyse, map, and monitor ecosystem patterns and processes"* (p.1,861).

2.5.1 Remote Sensing of Penguins: Guidance from Salient Case Studies

To be able to assess the response of penguins to climate change and other threats, it is clear that accurate estimates of species are needed at regular intervals (Waluda *et al.*, 2014), with remote sensing applications making the attainment of such data far more feasible for the polar regions than previously possible.

The two research objectives, the methodologies designed, and investigations undertaken (see chapters 5 to 8), were specifically developed with this in mind, and as a reflection of observations made from recent, comparable, studies. The most pertinent studies are referred to below and as appropriate to each of the two research objectives.

Objective 1: Population Census - Context

Several iterations are possible, here. One of the earliest applications of satellite remote sensing to estimations of penguin population status was undertaken by Schwaller *et al.* in 1989 who determined that the unique '*spectral signature*' of Adélie guano could be used to determine the presence of rookeries utilising pre-defined (laboratory analysed) reflectance measurements. Whilst the effects of slope (inclination) and shadows were acknowledged as being strong influencers of the recordings, as they are still liable to be today, the work was ground-breaking in its time but, surprisingly, was not revisited until recently, notably, with the research of Fretwell *et al.*, and Lynch *et al.* (both in 2014).

Trathan's work of 2004 has proved seminal, particularly in terms of the design of this research, determining that aerial photography provided the most reliable method for providing census information for large colonies. The advent of sub-metre satellite imagery may result in a requirement for reappraisal, but the statement remains true at present. Due to the labour-intensive and laborious nature of manually counting individuals or nests from imagery, Trathan developed an 'automated' counting approach using computer algorithms and image analysis techniques, finding that the counts correlated very positively with those from *actual* ground counts, albeit with caution required in terms of adopting the methodology for complex terrains, such as those having steep inclines and uneven relief producing pronounced shadowing effects. The imagery used for the research described herein, therefore, incorporated a digital elevation model (DEM) allowing for ortho-rectified imagery that is largely fee of topographically-related distortion (see chapter 5, onwards).

Following the work of Trathan, Barber-Meyer *et al.* (2007) worked with both panchromatic (black and white) and multispectral (blue, red, green and near-infrared spectral bands) satellite imagery of Emperor penguins (*Aptenodytes forsteri*) to establish the minimum abundances for colonies, backed-up by ground-counting where feasible. Using a semi-automated approach to classify pixels as penguins within images, they found that the approach was useful for detecting broad population changes within and among colonies, although the use of such satellite remote sensing (at the time) was not determined to be as accurate as either aerial or ground counts. Further, and as with the constraints imposed by the terrain in Trathan's earlier work, this analysis was hampered by "*excessive guano and shadows*" (p.1,565). Modifying this approach, Fretwell *et al.* (2012) found that the use of four spectral bands together with modifying the image via a process known as 'pansharpening' allowed much greater differentiation within images of penguins from snow, guano and shadows, providing the "*first synoptic survey of an entire population of a single species…using satellite remote sensing*" (p.3). Ancel *et al.* (2014) undertook similar work, corroborating the fact that ground-truthing and aerial photography remain essential approaches, particularly in relation to research within Antarctica with satellite remote sensing being particularly hampered by such variables as darkness, cloud cover, and snow.

Objective 2: Area Density - Context

Woehler & Riddle (1998) were amongst the earliest pioneers of the 'area density' approach, and attempted to establish whether the area of a colony as measured from aerial or satellite imagery could be used to accurately estimate population density (and, therefore, to detect changes in populations over time). There has been surprisingly little progress made with this approach in the intervening years, a few noteable exceptions aside. Similar to Schwaller *et al.* (1989), and setting aside the inherent – and acknowledged – limitations of the work (i.e. it concerned one species, in one area, over one season, only), the research may now be viewed as being of great importance, and is thought to have influenced in-part more recent endeavours such as described by McNeill *et al.* (2011), and Waluda *et al.* (2014), with such contemporary observers positing that the relationship of the area of a colony and the density of nests within that colony *can* be used to establish accurate estimates of total population size for that colony.

The few records of nesting densities that do exists are detailed with table 2-1. However, it is immediately evident that the results are few and vary considerably and thus may not be viewed as being particularly apposite to the research in hand, other than for the work of Stonehouse (1975) (see chapter 5, onwards).

Woehler & Riddle (1998) further determine that the estimating of population changes based on using aerial and satellite imagery to obtain colony area can present certain pronounced difficulties, namely that populations within colonies can increase in one of three ways:

- an increase in the area of a colony but density remains the same;
- an increase in both the area of a colony and the nesting density; and,
- an increase in the nesting density but the area occupied by the colony remains the same;

But that, in general, there is a positive correlation between colony population and density may be confidently expected, i.e., as population increases, so the density increases too.

Of additional relevance in terms of the current research, is that population census counting of penguins is known to be difficult unless a reliable relationship between total bird count and colony area can be established based on an assumed density per area (Woehler & Riddle, 1998) and that area has been found to positively correlate with estimates of the total number of nests – to an accuracy of 89% for Adélie, 87% for gentoo, and 75% for chinstraps, at colonies on the South Orkney Islands (Waluda *et al.*, 2014).

Table 2-1 Mean Recorded Nesting Densities amongst *Pygoscelid* Penguins

Source	Location	Adélie Penguin	Chinstrap Penguin	Gentoo Penguin
Stonehouse (1975)	Antarctic Peninsula 'region'	75.45cm[a]	86.4cm[b]	103.4cm[c]
Woehler & Riddle (1998)	979 colonies on 19 islands situated offshore of Mawson Research Base	63cm +/- 3cm	Not recorded	Not recorded
Davis *et al.* (1990)	King George Island, South Shetland Islands	37cm +/- 8mm	Not recorded	Not recorded
Waluda *et al.* (2014)	King George Island, South Shetland Islands	Not recorded	52cm +/- 1.5cm	Not recorded
	Approx. Mean (All Records)	**~59.12cm**	**~70.08cm**	**103.4cm**

Key:
[a] Based on four rookeries with average nest distances of between 66.9 to 84cm.
[b] The average from five rookeries.
[c] The average from four colonies with distances of between 92.1cm and 119.2cm.

However, there has been very little testing of the above principles, particularly with regards to the application of the approach to determining individual species within colonies of sympatric breeders. The methodologies described within this thesis will, it is to be hoped, begin to address this deficit in our knowledge.

Lastly, the advent of sub-metre satellite imagery such as that which will be provided from the imminent (2016) launch of the WorldView4 satellite is, perhaps, the most exciting of all new advances. The WorldView4 satellite will, it is understood, be able to discern objects as small as ~34cm in size on the Earth's surface within the panchromatic band, significantly improving current capabilities. It can be confidently expected that such advances will further highlight and solidify the imperative importance of remote sensing for conservation management.

3.0 Genus and Species of Interest

3.1 Antarctic Penguins: An Overview

With the oldest penguin fossils dating back to c. 55 million years before the present (Davis & Renner, 2003), penguins (*Spheniscidae*[17]) have evolved over the ages to become one of the key predators within the Antarctic and Southern Ocean ecosystems, consuming an estimated 24 million tonnes of prey per annum. However, whilst George Murray Levick, a zoologist on Robert Falcon Scott's 'Terra Nova Expedition' of 1910-1913, pronounced that the "*penguins of the Antarctic regions very rightly have been termed the true inhabitants of that country"* (Murray Levick, 1914, p.1), their biology and ecology remain understudied (Croxall, 1999), despite an otherwise wealth of general literature on the penguin family.

3.2 *Pygoscelid* Penguins

The 'brush-tailed' or *Pygoscelid* penguins are the archetypical black and white penguins depicted in cartoons (Davis & Renner, 2003). The genus comprises three congeneric species: the Adélie penguin (*Pygoscelis adeliae*), the chinstrap penguin (*Pygoscelis antarctica*), and the gentoo penguin (*Pygoscelis papua*). Whilst the species are monomorphic (Polito *et al*., 2012), they are however easily identifiable by the plumage of their heads (Simpson, 1976).

3.2.1 Chinstrap Penguin (Pygoscelis antarctica)

The chinstrap penguin, *Pygoscelis antarctica*, (plates 3-1 and 3-2), previously known as the 'ringed penguin', is essentially confined to the Antarctic Peninsula, the Scotia Arc islands, the South Sandwich Islands, and to South Georgia; roughly equating to a geographical distribution from 54ºS to 69ºS (Davis & Renner, 2003). Chinstrap penguin colonies can be enormous but the colonies at Cape Shirreff (section 4.3 and chapter 5.0, onwards) are considerably smaller. The species usually prefers to breed on the slopes of hillsides and sometimes even quite vertiginous cliff faces, as opposed to its congener, the gentoo penguin,

[17] See appendix 1 for the full taxonomic classification.

which prefers flatter terrain. Egg-laying and chick rearing typically take place between the middle of November and the middle of February[18].

As with most species within the Antarctic, historical data is limited and largely anecdotal. Determining trends in numbers, so essential for conservation, is therefore very difficult but the sporadic historical records that do exist, suggest that between the 1930s and 1970s, very significant increases in chinstrap penguins occurred across its range but that the increases were not sustained and that populations have declined precipitously since (Trivelpiece *et al.,* 2011), and by a magnitude of up to 50% in most areas, albeit with periodic increases consistent with the known significant interannual variability of the genus as a whole. At present, there are believed to be between c. 6.5 and 7.5 million breeding pairs of chinstrap penguins, making the species by far the most numerous of the genus, but with the wide range in estimates being further testament to a lack of basic census information. Whilst such numbers would seemingly point to healthy populations of the species, as far back as for the 1912 season, Murphy describes the *"diminution in the number of penguins"* (p.103, 1915), and contemporary observers agree that populations are declining as a whole and will continue to decline.

Indeed, Korczak-Abshire *et al.* (2012) note that at two chinstrap colonies on two of the islands of the South Shetland Islands (King George Islands and Penguin Island), breeding populations decreased by 84% and 41%, respectively, over the last three decades. Further, and particularly salient for the research in hand, the authors note that a "*similar trend has been observed on Livingston Island since the mid-1970s, as well as for the entire Western Antarctic Peninsula"* (p.1).

The warming currently being experienced in the WAP and Scotia Sea and sea ice decline (and, consequently, localised krill biomass decline) are particularly critical issues for the chinstrap penguin given it breeds almost exclusively within these areas and does not have any breeding refuges further south to migrate to.

[18] The typical life-cycle is: foraging from mid-April to mid-October; settlement from mid-October to mid-November; egg-laying from mid-November to mid-December; chick-rearing from January to mid-February, and; moulting from mid-March to mid-April (Borboroglu & Boersma, 2013).

Plate 3-1 The Chinstrap Penguin, *Pygoscelis antarctica*

Source: Photograph Courtesy of Dr. Gareth Rees, SPRI

Plate 3-2 Close-up of Chinstrap Penguin, *Pygoscelis antarctica*

Source: Photograph Courtesy of Dr. Gareth Rees, SPRI

Such is the concern for the species, that some specialists are calling for the International Union for the Conservation of Nature (IUCN) to review the status of the species[19]. As Trivelpiece *et al*. (2011) state: "*the chinstrap penguins may be among the most vulnerable species affected by a warming climate"* (p.7,628).

3.2.2 Gentoo Penguin (Pygoscelis papua)

The gentoo penguin (*Pygoscelis papua*) (plates 3-3 and 3-4), is the most northerly distributed of the three species of the *Pygoscelis* genus, with an Antarctic and sub-Antarctic distribution from c. 46ºS to 65ºS. The total population for the species is thought to be between c. 298,000 and 384,000[20] breeding pairs, far less than for either the Adélie or the chinstrap penguin, with colonies subsequently far smaller too[21]. As noted earlier, for all three species of the genus, populations are subject to pronounced inter-annual variability, both in terms of the number of breeding pairs and with regards to breeding productivity (Trathan *et al.*, 2008). Catastrophic breeding failure is also not unknown at gentoo colonies for which the majority of the diet is comprised of Antarctic krill, *Euphausia superba* (Pistorius *et al.*, 2010); whilst Baylis *et al.* (2012) recount that previous population declines within the Falkland Islands, notably between 2000 and 2005, was attributed in part to harmful algal blooms.

Unlike the chinstrap penguin, the gentoo prefers to build nests on low, flat, areas where their typically large nests may be widely spaced. Dependent on the location of the colony, nests tend to be composed of vegetation (typically, sub-Antarctic islands) or pebbles (Antarctic Peninsula and Scotia Arc), and with a generally northerly aspect (Quintana, 2001). Interestingly for the design of future monitoring campaigns, Davis (1990) found that 64% of gentoo penguins were faithful to their previous years' nesting territory, as compared to a much higher nest fidelity rate of 94% for chinstrap penguins (and 99% for Adélie). The

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[19] The IUCN publishes the 'red list of threatened species' which highlights species threatened with extinction. Currently, the chinstrap penguin is noted as being "*of least concern*" in terms of its conservation status. However, the threats faced by the species, notably due to a warming climate, have led to calls for a review of its status. In the hierarchy of IUCN classifications, the next classification is of a species being recognised as "*vulnerable*", which would serve to highlight the plight of the species and the need for conservation measures.

[20] 298,000 (Quintana & Cirelli, 1998); 300,000 (Davis, 1990); 317,000 (Davis & Renner, 2003) and; 384,000 (Baylis *et al.*, 2012)

[21] Ainley *et al.* (1995) counted 24,016 pairs of gentoo penguins along the Antarctic Peninsula and Scotia Arc (including Livingston Island), within 42 colonies, giving an 'average' colony size of 571 pairs.

period of egg-laying and chick rearing for the species typically[22] begins in the middle of November.

Gentoo colonies are usually smaller than for the other two species and, importantly for the current research, colonies tend to be far less densely packed (Davis & Renner, 2003). In addition, the species is typically non-migratory, preferring to remain around its breeding colonies year round and having an affinity to returning to shore each day (*inter alia*: Fraser *et al.,* 1992; Croxall & Davis, 1999: Hinke, 2012, unpublished; Clucas *et al.*, 2014). This would perhaps suggest that the species would have a long history of having been monitored but, in fact, the gentoo penguin appears to be the least well understood of all the penguin species (Davis & Darby, 1990).

In contrast to the sea ice-obligate Adélie penguin, and chinstrap penguin to a lesser degree, the variability in sea ice extent and duration is not thought to typically affect gentoo penguin populations unless its extent impedes access to breeding colonies. Further, the species has a more varied diet and, at most colonies (although not for Cape Shirreff), is far less dependent on Antarctic krill than its other congeners, relying on fish[23] at different times, typically diving far deeper than the Adélie or chinstrap penguin, thus allowing the species to exploit resources (including deep-lying krill swarms and demersal fish, crustaceans, and squid) not available to the other two species (Trivelpiece & Volkman, 1987). These factors would seem to indicate, at a broad scale at least, that the species may be more resilient to change in the form of climate warming than for the two other *Pygoscelid* species; an hypothesis that is perhaps borne out by records suggesting the species is expanding its range southwards into areas traditionally dominated by both Adélie penguin and chinstraps (*inter alia*: Forcada *et al*., 2006; Hinke, 2012; Pena *et al*., 2014). However, given the pronounced inter-annual variability, the danger of colony-extinctions, and that declines have been noted at several key colonies within the sub-Antarctic region, the IUCN denotes the species' conservation status as being 'near threatened[24]'.

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[22] The annual breeding cycle of the gentoo penguin is under-researched but an approximate timetable would be: egg laying, between the middle of November and middle of December; hatching between mid-December and early January; creching between early and late January; and, fledging between late January and the middle of February (modified from *pers. comm. with* Dr. Phil Trathan, BAS, 09.04.15).

[23] Croxall & Davis (1999) describe the icefish (*Champsocephalus gunnari*) as the main fish species eaten by the gentoo penguin. The icefish is confined to the continental shelf area, perhaps explaining in-part the reason why the gentoo penguin is generally an in-shore feeder.

[24] IUCN: http://www.iucnredlist.org/details/22697755/0

Plate 3-3 The Gentoo Penguin, *Pygoscelis papua*

Source: Photograph Courtesy of Dr. Gareth Rees, SPRI

Plate 3-4 Gentoo Penguin (*Pygoscelis papua*) and Chick

Source: Photograph Courtesy of Dr. Gareth Rees, SPRI

3.3 Pygoscelid Records for Cape Shirreff

3.3.1 Historical Records

South Shetland Islands Records

As intimated earlier, historical records for the genus within the region as a whole are relatively rare with many observers also questioning the accuracy of the historical records that do exist. Contemporary observations do not suffer from such concerns but remain generally sparse, due in the main to the harsh and remote environs in which the colonies are situated.

However, without long-term historical data and contemporary, on-going, monitoring of populations, it is very difficult to fully ascertain the relationship between the physical and biological environment and penguin demographics. With this in mind, table 3-1 has been included, to provide a salient depiction of the general paucity of data available on the two species at the South Shetland Islands, other than for Cape Shirreff. Despite its brevity, the historical records presented within this table represent the findings collated from the analysis of over 150 articles within available published sources. Clearly, it would be very difficult to make any robust argument based on such insufficiency.

Further, and although the species are typically sympatric breeders, certain factors are thought to have dictated the respective ecological niches of the three species, and thus the extent of their respective geographic ranges, and include differences in: breeding chronologies and life cycles; and in foraging ranges (with Ainley *et al*., 1995, finding that Adélie penguins at King George Island, South Shetland Islands, had the greatest foraging range of the genus at 50 km, whilst chinstrap and gentoo typically foraged to a distance of 27 km and 17 km, respectively). With this in mind, Trivelpiece *et al.* (1987) and Forcada *et al.* (2006) determine that ecological niches are resultant from the environments that the species find towards the centres of their respective geographic ranges and the physiological adaptations that have ensued. Thus, for example, for gentoo penguins, whose range extends farther north than that of the other two species of the genus, the non-migratory behaviour coupled with non-fasting and the slow-growth of chicks is, it is contended, in response to the milder climate experienced at such latitudes; whilst, chinstrap penguins typically breed far later than for sympatric Adélie penguins within the maritime Antarctic, thereby increasing the probability of the presence of ice-free seas.

Table 3-1 Compilation of Historical Records for Breeding Pairs of *P. antarctica* & *P. papua* for the South Shetland Islands (Excluding Cape Shirreff)

Reference	Date of Records	Chinstrap Populations (*P. antarctica*)	Gentoo Populations (*P. papua*)	Comment
Stonehouse (1975)	Compilation of records [a]	~50,000	~800	Harmony Cove, Nelson Island.
		~15,000	Unknown	The Toe, Nelson Island.
		~500	~2,000	Ardley Peninsula, King George Island.
		~200	~1,000	Strange Point, King George Island.
	1957	Unknown	50	Barnard Point, Livingston Island.
	1965	Unknown	264	Barnard Point, Livingston Island.
	1957	Unknown	1,000[b]	Point Thomas, King George Island.
	1965	Unknown	2,152	Point Thomas, King George Island.
	1975	Unknown	500	Cape Lion Rump, King George Island.
	1965	Unknown	1,500	Cape Lion Rump, King George Island.
	1956	Unknown	200 to 500	Cape Shirreff, Livingston Island.
Croxall & Furse (1980)	1980 (?)	430,000	2,600	Elephant Island & Clarence Island, in their entirety.
		10,700	Unknown	Chinstrap Cove, Clarence Island.
		91,000	Unknown	Cape Bowles, Clarence Island.
		6,000	Unknown	The Spit, Gibbs Island.
		8,800	Unknown	Camp Corrie, O'Brien Island.
Croxall (1986)	Undated; compilation of records	107,000[c]	~8,400[d]	Collated records pertinent to the CCAMLR identified ASPAs and SSSIs [e].
		2,000	>500	Cape Shirreff records (1958 record).
		100	2,000	Fildes Peninsula, King George Island.
		5,500	1,150	Byers Peninsula, Livingston Island.
		10,500	3,500	Western Shore, Admiralty Bay, King George Island.
		50,000	Unknown	Harmony Cove, Nelson Islands.
Davis & Darby (1990)	Undated	Unknown	17,200	South Shetland Islands in their entirety.
Aguirre (1994)	1987 – 1989	265	2,325	Potter Peninsula, King George Island.
Young (1994)	1983	6,000	57,000	King George Island (specific location/s not noted).
Lumpe & Weidinger (1998)	1998	800	Unknown	Nelson Island.

Key:
[a] Count of the number of nests.
[b] Individual birds.
[c] Recorded from 5 SPA and 4 SSSIs
[d] Recorded from 2 SPA and 5 SSSIs but data deficient.
[e] Sites of Special Scientific Interest (SSSIs) have in some instances been renamed as Antarctic Specially Protected Areas (ASPAs).

Cape Shirreff Historical Records

Whilst Trivelpiece *et al.* (2011) refer to historical records for the genus for the wider Antarctic region dating back to the 1930s, the earliest records for Cape Shirreff *per se* appear to be from the 1956/57 season, and as reported by Croxall in 1979 (and 1986), who counted c. 2,000 chinstrap penguins and between 200 and 500 gentoo penguins at the Cape.

There do not appear to be any further published monitoring records from Cape Shirreff until 1981 and which were recorded by the United States Antarctic Marine Living Resources (US AMLR) program[25] (*sic*). The US AMLR note that in 1981, 2,164 chinstrap and 843 gentoo penguins were counted at the Cape; whilst in 1987, 5,200 and 300 chinstrap and gentoo penguins, respectively, were recorded.

Post-1987, the next records published were in 1997 when the US AMLR launched a pilot monitoring study of species at Cape Shirreff. This reflected the findings of the 1996-1997 austral summer season at the US Cape Shirreff station, and from when annual surveys have been undertaken ever since.

The findings of all US AMLR monitoring campaigns from 1997-1998[26] onwards have been synthesised and summarised within table 3-2, with additional analysis as deemed useful; and from which the graphs presented at figures 3-1 and 3-2 have been developed and included for ease of comparison and assessment.

From figure 3-2, the considerable inter-annual variation in populations is clear to see, whilst the following inferences may also be made from the 13 seasons for which data is available:

- that an inverse negative correlation appears to exist for 4 of the 13 seasons (2000-01; 2004-05; 2009-10; 2010-11); three of which show a year-on-year decrease in chinstrap nests at the rookery but an increase in the nests of gentoo penguins; whilst one of the years, 2009-10, shows the reverse of this;
- that only two of the seasons (or 15%), 1999-00 and 2008-09, showed year-on-year increases in the number of nests for both species during the same period;

[25] US AMLR, part of the National Oceanic and Atmospheric Administration (NOAA): https://swfsc.noaa.gov/aerd/

[26] The first full season of monitoring; the 1996-1997 campaign was a pilot study of limited duration and counted chicks rather than breeding pairs.

- that the two surveys periods 2007-08 and 2008-09 show by far the most noteworthy of results, with very large year-on-year decreases in the 2007-8 season, and correspondingly pronounced increases the following season (2008-09). The US AMLR have attributed the significant decreases in chinstrap (c.33%) and gentoo (c.22%) nests during the 2007-08 season to, in part, "*unusually deep snow cover and frequent snow storms around the time of egg-laying"* (Van Cise, 2008, p.114). The significant increases in nests recorded for the following year, c.33% and c.44% increases for chinstrap and gentoo nests, respectively, "*could be interpreted as a rebound*" (Van Cise, 2009, p.35) from the low counts of the previous season, but no further inferences are made; and,
- of the 4,130 nests identified, ~80% (or 3,291) were chinstrap penguin nests, and ~20% (840) were gentoo penguin nests, reflecting the relative global abundance of the chinstrap penguin when compared with the gentoo.

Figure 3-1 has also been compiled to allow for a graphical representation of *all* records for Cape Shirreff, including both the US AMLR annual surveys and the individual records for the years 1956, 1981, and 1987. This graph clearly shows the general trend of decline in the chinstrap penguin population at the Cape Shirreff rookery.

Table 3-2 Historical Chinstrap (*P. antarctica*) and Gentoo (*P. papua*) Colony Counts at Cape Shirreff 1996 - 2011

Season (Years)	No. of Colonies	No. of Chinstrap Breeding Pairs (Chicks)	No. of Gentoo Breeding Pairs (Chicks)	% Difference – Year-on-Year: Chinstrap & Gentoo	% Difference – Compared to Max Year: Chinstrap & Gentoo	Comment
1996-1997	30 breeding colonies, comprising: 19 chinstrap colonies 6 gentoo colonies 5 mixed chinstrap & gentoo colonies	(8,752 Chicks)	(825 Chicks)	N/A	N/A	This was a pilot study, only, in order to inform the design of future studies.
1997-1998	30 breeding colonies, comprising: 19 chinstrap colonies 6 gentoo colonies 5 mixed chinstrap & gentoo colonies	7,617 Breeding Pairs	810 Breeding Pairs	N/A	Chinstrap: -1.64% Gentoo: -22.34%	First full season of research, therefore comparison not possible with earlier years.
1998-1999	30 breeding colonies, comprising: 19 chinstrap colonies 6 gentoo colonies 5 mixed chinstrap & gentoo colonies	7,581 Breeding Pairs	830 Breeding Pairs	Chinstrap: -0.47% Gentoo: +2.47%	Chinstrap: -2.1% Gentoo: -20.42%	
1999-2000	30 breeding colonies, comprising: 19 chinstrap colonies 6 gentoo colonies 5 mixed chinstrap & gentoo colonies	**7,744** Breeding Pairs	922 Breeding Pairs	Chinstrap: +2.15% Gentoo: +11.08%	Chinstrap: 0% Gentoo: -11.6%	The zenith of breeding pairs of chinstrap penguins monitored during the survey period.
2000-2001	29 breeding colonies, comprising: 16 chinstrap colonies 7 gentoo colonies 6 mixed chinstrap & gentoo colonies	7,212 Breeding Pairs	**1,043** Breeding Pairs	Chinstrap: -6.87% Gentoo: +13.12%	Chinstrap: -6.87% Gentoo: 0%	The zenith of breeding pairs of gentoo penguins monitored during the survey period.
2001-2002	28 breeding colonies, comprising: 13 chinstrap colonies 7 gentoo colonies 8 mixed chinstrap & gentoo colonies	6,606 Breeding Pairs	907 Breeding Pairs	Chinstrap: -8.4% Gentoo: -13.04%	Chinstrap: -14.7% Gentoo: -13.04%	

Table 3-2 (cont.) Historical Chinstrap (*P. antarctica*) and Gentoo (*P. papua*) Colony Counts at Cape Shirreff 1996 – 2011

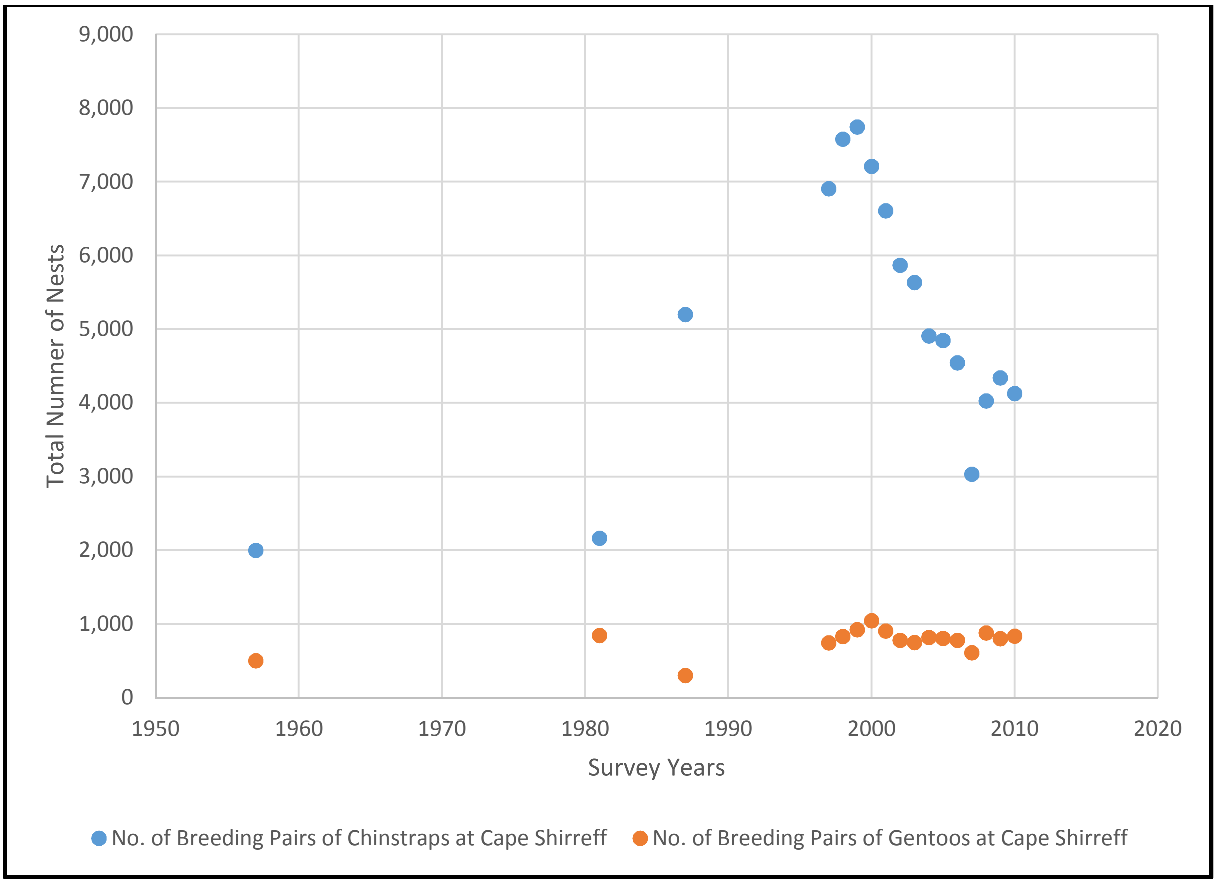
Season (Years)	No. of Colonies	No. of Chinstrap Breeding Pairs (Chicks)	No. of Gentoo Breeding Pairs (Chicks)	% Difference – Year-on-Year: Chinstrap & Gentoo	% Difference – Compared to Max Year: Chinstrap & Gentoo	Comment
2002-2003	26 breeding colonies, comprising: 13 chinstrap colonies 7 gentoo colonies 8 mixed chinstrap & gentoo colonies	5,868 Breeding Pairs	778 Breeding Pairs	Chinstrap: -11.17% Gentoo: -14.23%	Chinstrap: -24.22% Gentoo: -25.41%	
2003-2004	25 breeding colonies	5,636 Breeding Pairs	751 Breeding Pairs	Chinstrap: -3.75% Gentoo: -3.47%	Chinstrap: -27.22% Gentoo: -28.00%	Reports from 2003, onwards, do not further elaborate on exact division of colonies per species or mix of species.
2004-2005	23 breeding colonies	4,907 Breeding Pairs	818 Breeding Pairs	Chinstrap: -12.93% Gentoo: +8.92%	Chinstrap: -36.63% Gentoo: -21.57%	
2005-2006	22 breeding colonies	4,849 Nests	807 Nests	Chinstrap: -1.18% Gentoo: -1.34%	Chinstrap: -37.39% Gentoo: -22.62%	Reports from 2005, onwards, refer to the number of nests per species rather than the number of breeding pairs. However, as one nest may be assumed to comprise one breeding pair (two individuals), the statistics are still comparable.
2006-2007	22 breeding colonies	4,544 Nests	781 Nests	Chinstrap: -6.29% Gentoo: -3.22%	Chinstrap: -41.32% Gentoo: -25.12%	

Table 3-2 (cont.) Historical Chinstrap (*P. antarctica*) and Gentoo (*P. papua*) Colony Counts at Cape Shirreff 1996 – 2011						
Season (Years)	**No. of Colonies**	**No. of Chinstrap Breeding Pairs (Chicks)**	**No. of Gentoo Breeding Pairs (Chicks)**	**% Difference – Year-on-Year: Chinstrap (Gentoo)**	**% Difference – Compared to Max Year: Chinstrap (Gentoo)**	**Comment**
2007-2008	19 breeding colonies	3,032 Nests	610 Nests	Chinstrap: -33.27% Gentoo: -21.89%	Chinstrap: -61.85% Gentoo: -41.51%	2007-08 represents the largest reduction of chinstrap penguins from 1999-2000 high, & the largest reduction of gentoo penguin populations from 2000-2001 high; together with the largest year-on-year decreases for both species.
2008-2009	19 breeding colonies	4,026 Nests	879 Nests	Chinstrap: +32.78% Gentoo: +44.10%	Chinstrap: -49.01% Gentoo: -15.72%	2008-09 represents the largest year-on-year increase of both chinstrap and gentoo penguin populations during the study period.
2009-2010	19 breeding colonies	4,339 Nests	802 Nests	Chinstrap: +7.78% Gentoo: -8.76%	Chinstrap: -43.97% Gentoo: -23.11%	
2010-2011	19 breeding colonies	4,127 Nests	834 Nests	Chinstrap: -4.89% Gentoo: +3.99%	Chinstrap: -46.71% Gentoo: -21.04%	Last available historical dataset at time of writing; 2011-12 & 2012-13 not available.

Key: Green = year-on-year increase in the number of nests recorded; Red = year-on-year decrease in the number of nests recorded.

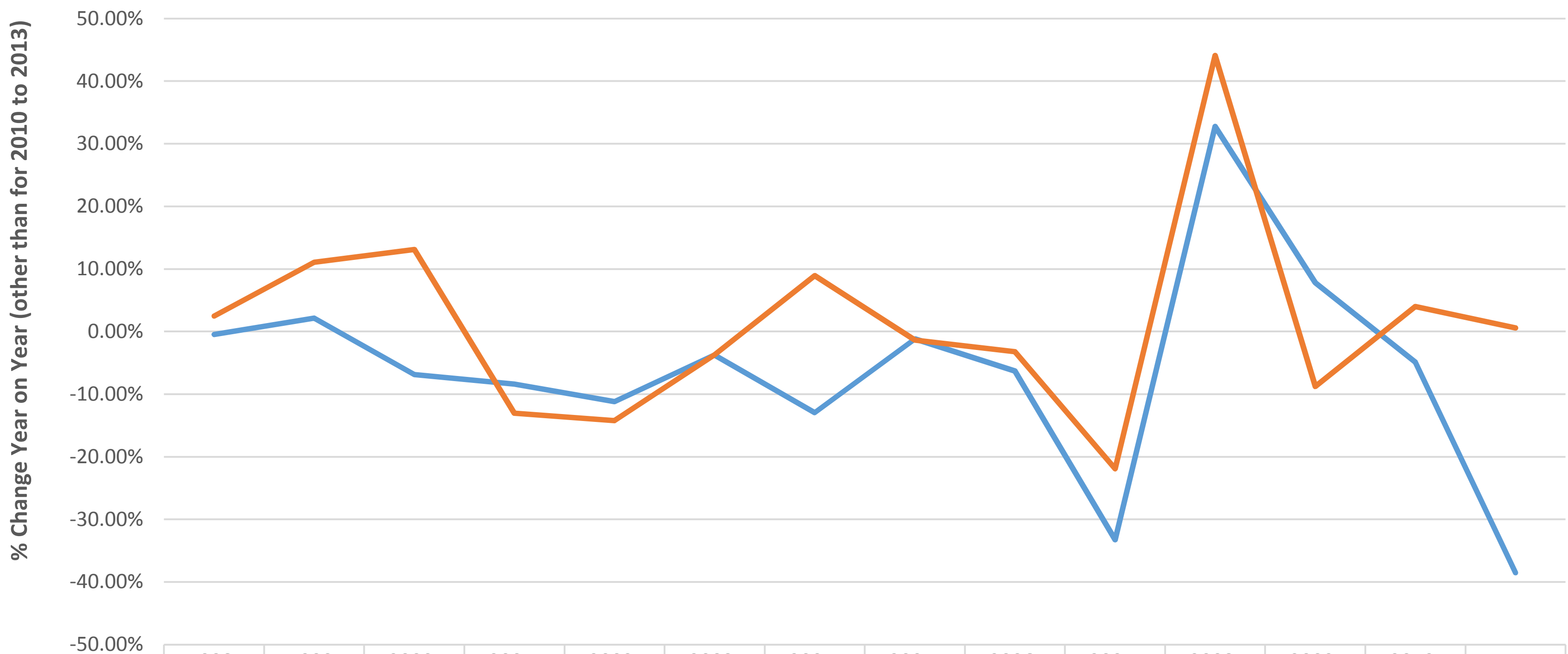
Source: Synthesized and adapted from United States Antarctic Marine Living Resources (AMLR) Program Reports, July 1997 to February 2014: https://swfsc.noaa.gov/textblock.aspx?Division=AERD&id=3154

Figure 3-1 Comparison of Total Chinstrap (*P. antarctica*) and Gentoo (*P. papua*) Penguin Populations at Cape Shirreff for All Available Survey Years[27] (1956; 1981; 1987; & 1998 to 2011)



[27] **Source**: Synthesised and adapted from United States Antarctic Marine Living Resources (AMLR) Program Reports, July 1997 to February 2012: https://swfsc.noaa.gov/textblock.aspx?Division=AERD&id=3154

Figure 3-2 Percentage Year-on-Year Change in Historical *Pygoscelid* Numbers for Seasons 1998 to 2011 & 2013-2014 – with Data Table



	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009	2009-2010	2010-2011	2013-14
Chinstraps: % Diff. Year-on-Year	-0.47%	2.15%	-6.87%	-8.40%	-11.17%	-3.75%	-12.93%	-1.18%	-6.29%	-33.27%	32.78%	7.78%	-4.89%	-38.50%
Gentoos: % Diff. Year-on-Year	2.47%	11.08%	13.12%	-13.04%	-14.23%	-3.75%	8.92%	-1.34%	-3.22%	-21.89%	44.10%	-8.76%	3.99%	0.60%

Survey Seasons & Population Changes in Percentages

Sources: Adapted from: United States Antarctic Marine Living Resources (US AMLR) Program Reports, July 1997 to February 2012: https://swfsc.noaa.gov/textblock.aspx?Division=AERD&id=3154; & Hinke, Jefferson (2015). US AMLR Field Data from Cape Shirreff for the 2013-2014 Season (*Pers. Comm.* via email from Dr. P. Trathan, BAS, 07.04.2015).

3.3.2 Contemporary Records

The latest currently available records from US AMLR data (table 3-3) are for the 2013-14 season (which is contemporaneous with the season that the BAS aerial photography was taken from that is examined later).

The following are particularly noteworthy in terms of the current research:

- of the 4,130 nests identified, ~61% (2,539) were identified within the eastern region and ~39% (1,591) within the western region of the rookery (see chapter 5). The reasoning for this is debatable but presumably the primary reasons will be ones of habitat preferences and lifecycle requirements;
- ~42% (355) and ~58% (485) of the gentoo populations were in the eastern and western regions, respectively; whereas, the bulk of chinstrap penguin nests occurred in the eastern region (~66% or 2,184 nests), with the western region accounting for just over a third of the records (~34% or 1,106); and,
- as noted within table 3-2, the last year for which US AMLR Cape Shirreff historical data – as opposed to the contemporary data for the 2013-14 season - is currently (at the time of writing) available is for the 2010-11 season. This data notes 19 colonies and identifies 4,127 chinstrap nests and 834 gentoo nests, giving a total of 4,961 breeding pairs for both species. However, the US AMLR findings for the 2013-14 season are of 3,582 and 840 nests of chinstrap and gentoo penguins, respectively, representing a very significant decline over the intervening three seasons of 38.5% in chinstrap breeding pairs, and a very moderate (c.0.6%) increase in gentoo nests This worrying decline in chinstrap populations at Cape Shirreff will be revisited within this thesis. Colonies may rebound as they did following a similar crash in numbers in the 2007-08 season but, on the face of it, such significant declines would seem to add to the argument for the re-designation of the species by the IUCN, whilst very clearly highlighting the real, urgent, need for up-to-date monitoring data for species not least in an effort to determine whether such significant population fluctuations are common throughout the species' range.

Table 3-3 Contemporary *P. antarctica* & *P. papua* Colony Counts at Cape Shirreff (2013-14)

US AMLR Colony Number	**US AMLR Ground Count Data (2013-14) Season**		
	Chinstrap	**Gentoo**	**Colony Total**
2[a]	291	0	291
3	709	31	740
5	81	82	163
6	0	130	130
8	74	94	168
9	30	0	30
10	464	18	482
11	399	0	399
12	53	0	53
13	107	0	107
14	267	0	267
17	0	56	56
18	0	135	135
20	91	34	125
21	0	7	7
22	0	33	33
23	65	120	185
24	0	99	99
27	13	0	13
29	938	0	938
Totals	**3,582**	**839**	
		Rookery Total	**4,421**

Note:
[a] Colony 2 is noted as a non-disturbance colony. As it is not possible to determine its location within the rookery, it is not included within future calculations (see chapter 5, onwards).

4.0 The Research Locations & Environmental Management

4.1 The South Shetland Islands

The South Shetland Islands are an archipelago of twenty or so islands, 11 of which (the ‘main’ islands) are quite sizeable, together with numerous islets (figures 4-1 to 4-3), and extending longitudinally for nearly 500 km, covering a total land area of c. 3,700 km^2. The Islands lie within a zone situated approximately 61º00’ to 63º37’ South, and 53º83’ to 62º83’ West; or about 1,100 km south of the Falkland Islands and c. 100 km at the nearest point from the Antarctic continent (as measured from Deception Island).

The Islands are situated at the eastern end of the Bellingshausen Sea, and the western part of the Weddell Sea. The waters surrounding the archipelago are often enclosed by sea ice, and typically from early April to early December each year. The climate is generally cloudy with very strong winds a particular feature and which blow throughout the year. The warmest months are in January and February, with a mean summer temperature of c. 1.5ºC; the mean winter temperature is c. -5ºC, with July generally the coldest month.

Despite on-going glacial retreat, c. 80% to 90% of the archipelago remain glaciated with, perhaps counterintuitively but not unusually, several active volcanic islands or islands with active volcanoes situated on them.

Due to their relatively close proximity to Tierra del Fuego (approximately 950 km), the South Shetland Islands are one of Antarctica’s most visited areas today, but they were not thought to have been ‘discovered’ until 1818 by the crew of the British merchant ship the ‘Williams’. The Williams returned in 1820 to chart the archipelago and by October of the same year, both British and American boats are recorded as having descended on the Islands to hunt the endemic seals, decimating populations in only three seasons. Initially known as ‘New South Britain’, the Islands were renamed as the South Shetland Islands during this period.

Figure 4-1 South Shetland Islands – Regional Context

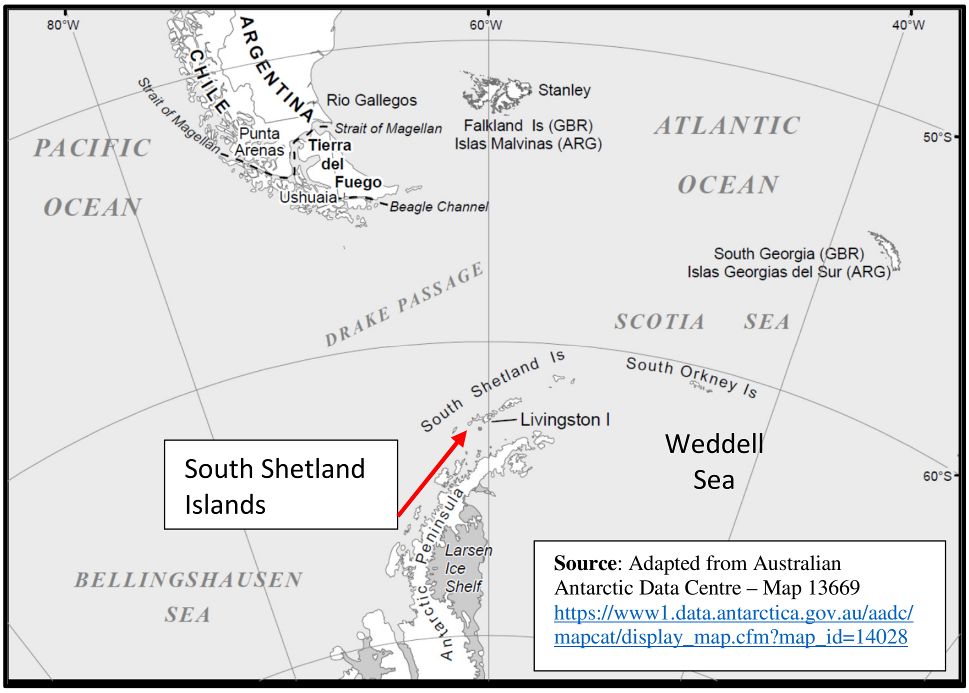
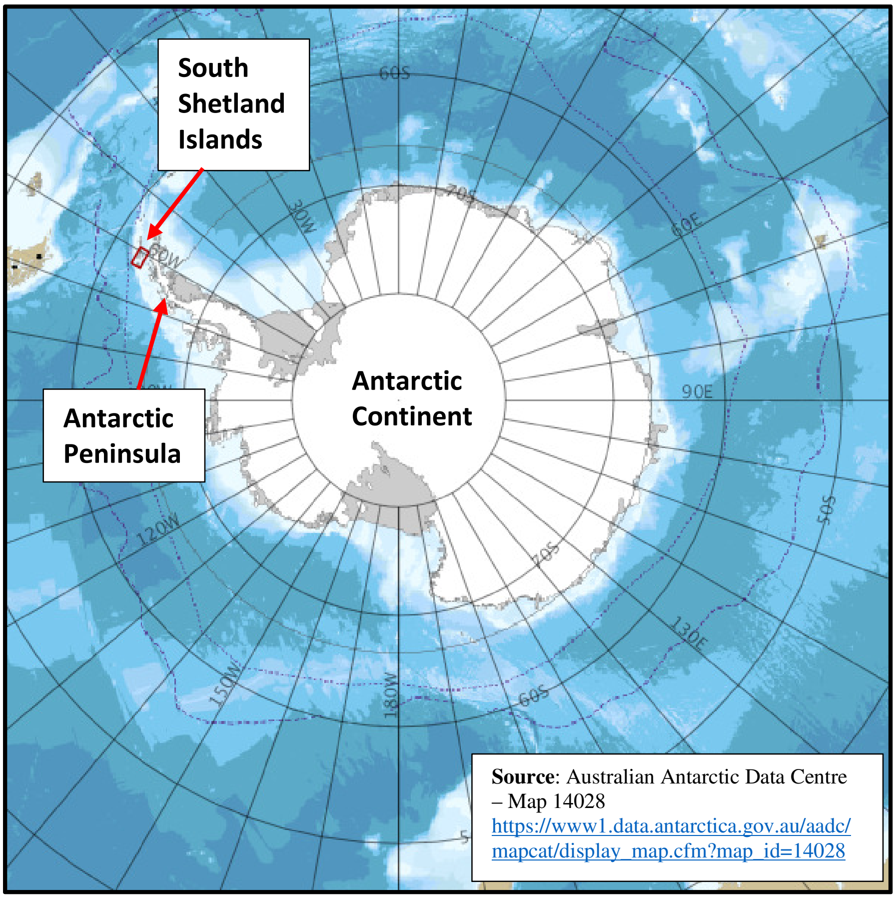
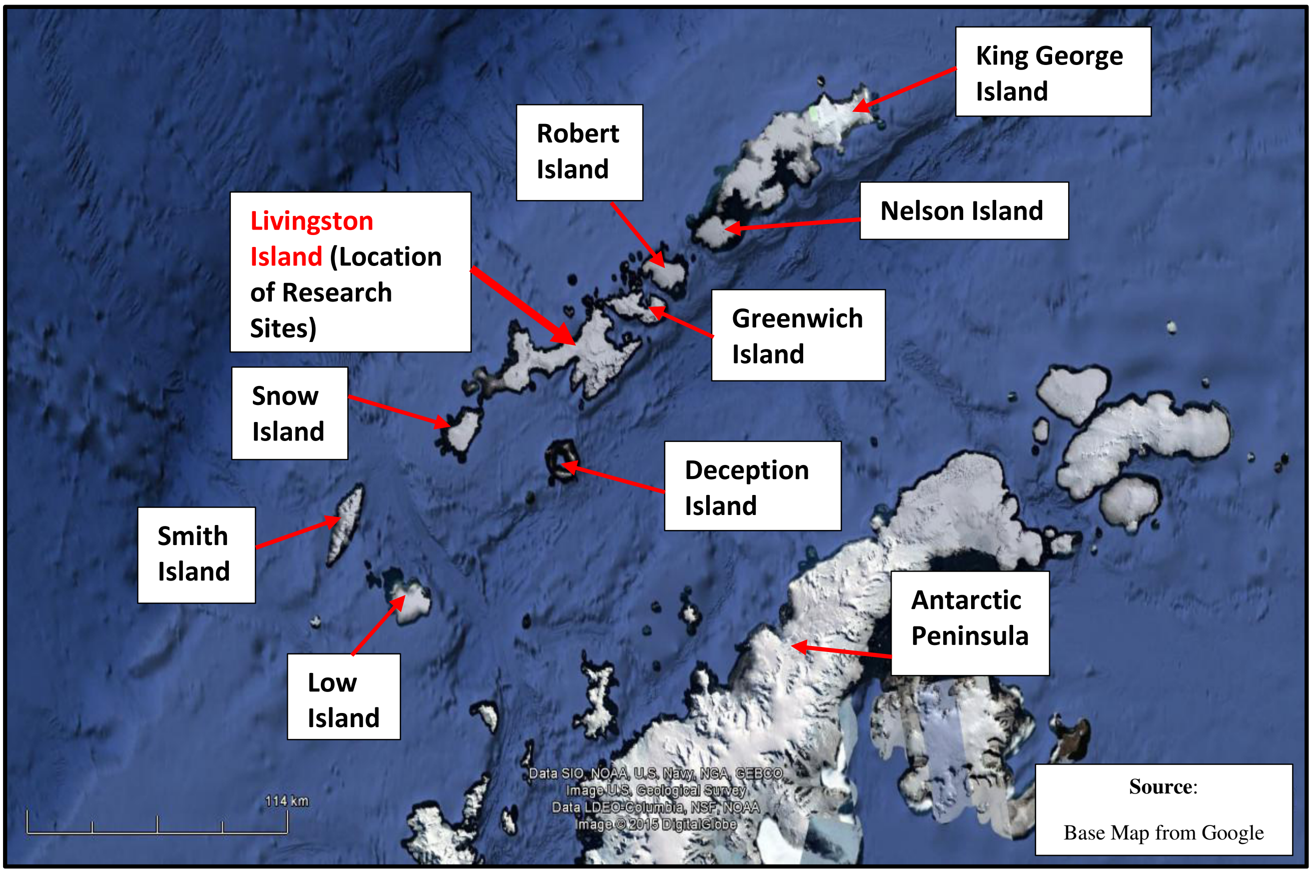


Figure 4-2 South Shetland Islands – In Relation to the Antarctic Peninsula & Continent



There are currently 16 research stations and field camps situated on the Islands, operated by several nations but with some shared between nations, such as the Chilean-US base at Cape Shirreff (section 4.3). No sovereign power has rights over the South Shetland Islands; as the Encyclopedia of Earth website notes: "*Under the Antarctic Treaty (1959) the Islands' [South Shetland Islands] sovereignty is neither recognized nor disputed by the signatories and they are free for use by any signatory for non-military use*".

Figure 4-3 Location of the Main Islands Comprising the South Shetland Islands



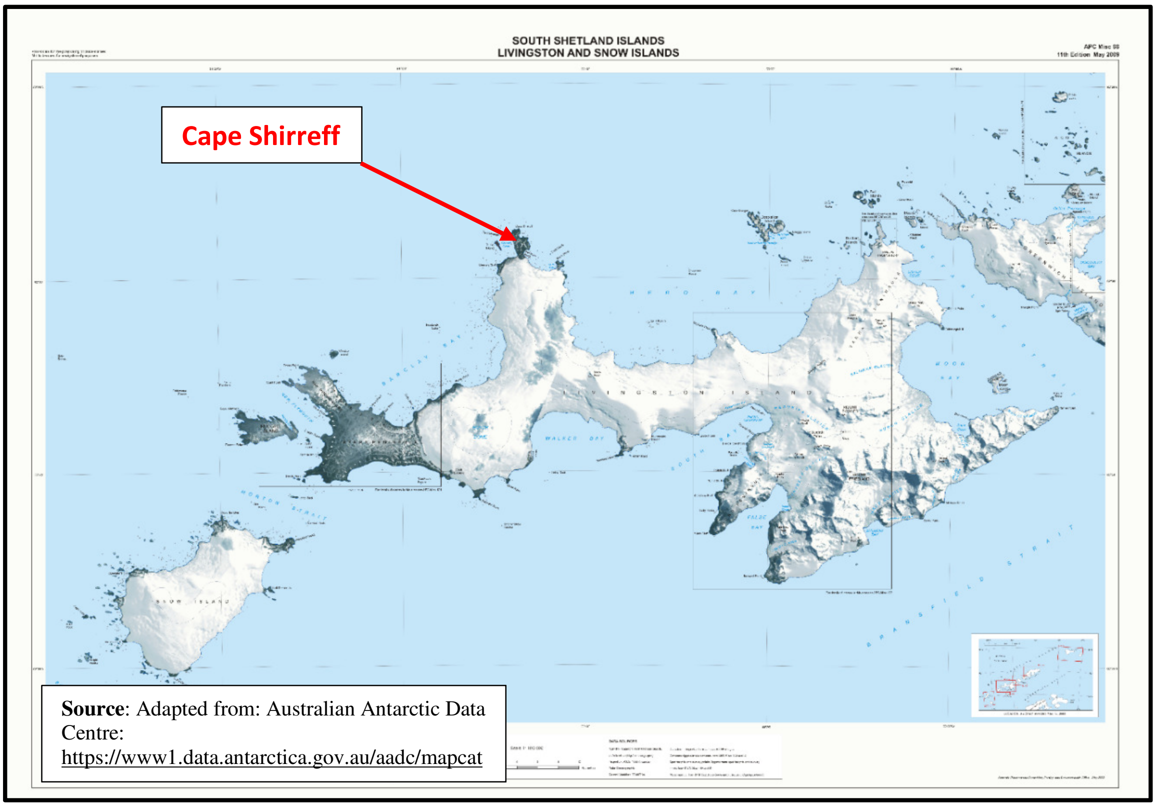
4.2 Livingston Island

Livingston Island[28] (figures 4-3 to 4-6), situated within a zone roughly equating to 62°36'S and 60°30'W, is the second largest of the South Shetland Islands (after King George Island), measuring c. 73 km by 34 km in extent on an axis running west-south-west to east-north-east, and equating to a total surface area of c. 798 km^2.

[28] British Antarctic Survey: http://www.antarctica.ac.uk/met/momu/International_Antarctic_Weather_Forecasting_Handbook/update%20Spain.php

The island is mainly covered by an ice cap and valley glaciers, with intermittent rocky outcrops and ice-free areas, such as the expansive Byers Peninsula to the west (figure 4-5), Hannah Point and William Point, the Hurd Peninsula, and Cape Shirreff (section 4.3). The eastern portion of the island is particularly mountainous with the highest mountain, Mount Friesland, part of the Tangra Mountains, being 1,770 m (5,800 ft) in height. The coast is deeply indented with a variety of fjords, peninsulas, and bays.

Figure 4-4 Livingston Island, South Shetland Islands



Source: Adapted from: Australian Antarctic Data Centre: https://www1.data.antarctica.gov.au/aadc/mapcat

Being located at the northernmost part of the Antarctic, and within the 'maritime Antarctic', the island has a relatively mild climate, with temperatures rarely falling below -11°C in winter, and generally hovering around 3°C in the summer, but with significant wind chill possible throughout the year. Whiteouts are also common on the island. Further, the island is located at the latitude of the 'Antarctic circumpolar trough[29]' (ACT) and is thus affected by

[29] The Antarctic circumpolar trough (ACT) is located between approximately 60°S and 65°S, and is a zone of low pressure that contains variable winds that blow from the west to the east. Within this region, ferocious storm systems gather warm, moist, air from mid-latitude areas and export them polewards, resulting in extensive cloud systems and prolonged precipitation. These pronounced storms typically last for a few days before clearing but after a short period of more temperate weather, further storms typically emerge.

numerous active depressions that pass through the Drake Passage (figure 4-1), with resultant gales and precipitation.

4.3 Cape Shirreff

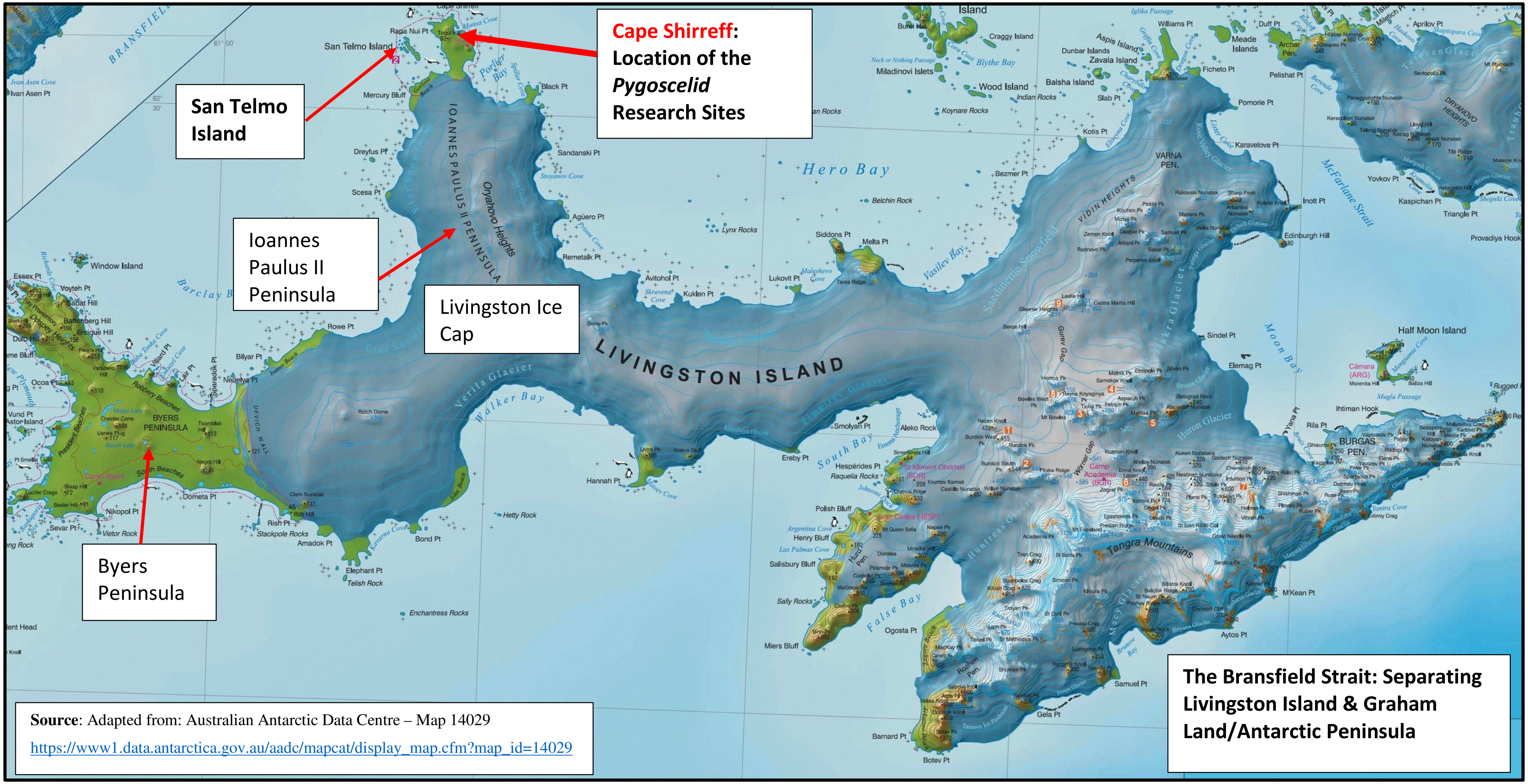
Cape Shirreff (figures 4-5 and 4-6), is a prominent headland on the north coast of Livingston Island. It is situated at the northern extremity of the 13 km long Ioannes Paulus II Peninsula (figure 4-5). It is an ice-free promontory of approximately 3.1 km^2 (c. 2.6 km from north to south, and ranging between 0.5 and 1.5 km east to west) . It is identified both as an Important Bird and Biodiversity Area (IBA)[30] and, together with San Telmo Island and the intervening seas, as an Antarctic Specially Protected Area (ASPA[31]) by the CCAMLR, particularly in lieu of its populations of chinstrap and gentoo penguins, but also due to important populations of Antarctic fur seals (*Arctocephalus gazelle*), Antarctic terns (*Sterna vittata*), Cape petrels (*Daption capense*), and imperial shags (*Phalacrocorax atriceps*).

Cape Shirreff is "*characterized by raised beaches and both steep and rolling hills rising to a maximum height of 82 m, with steep cliffs on the western coast and long sand and gravel beaches on the east"* (Birdlife International, 2015). Snow typically covers the peninsula for most of the year although it seldom remains over the summer months. The mean diurnal air temperature is recorded as being between 2.0 and 2.5°C.

[30] IBA's are identified by Birdlife International to "*ensure the survival of viable populations of most of the world's bird species*": http://www.birdlife.org/worldwide/programmes/important-bird-and-biodiversity-areas-ibas

[31] Article 3 of Annexe V of the Antarctic Protocol (or, fully, the Protocol on Environmental Protection to the Antarctic Treaty, 1991) determines that any area, including any marine area, may be designated as an ASPA so as to "*protect outstanding environmental, scientific, historic, aesthetic, or wilderness values*".

Figure 4-5 Livingston Island Showing Location of Cape Shirreff



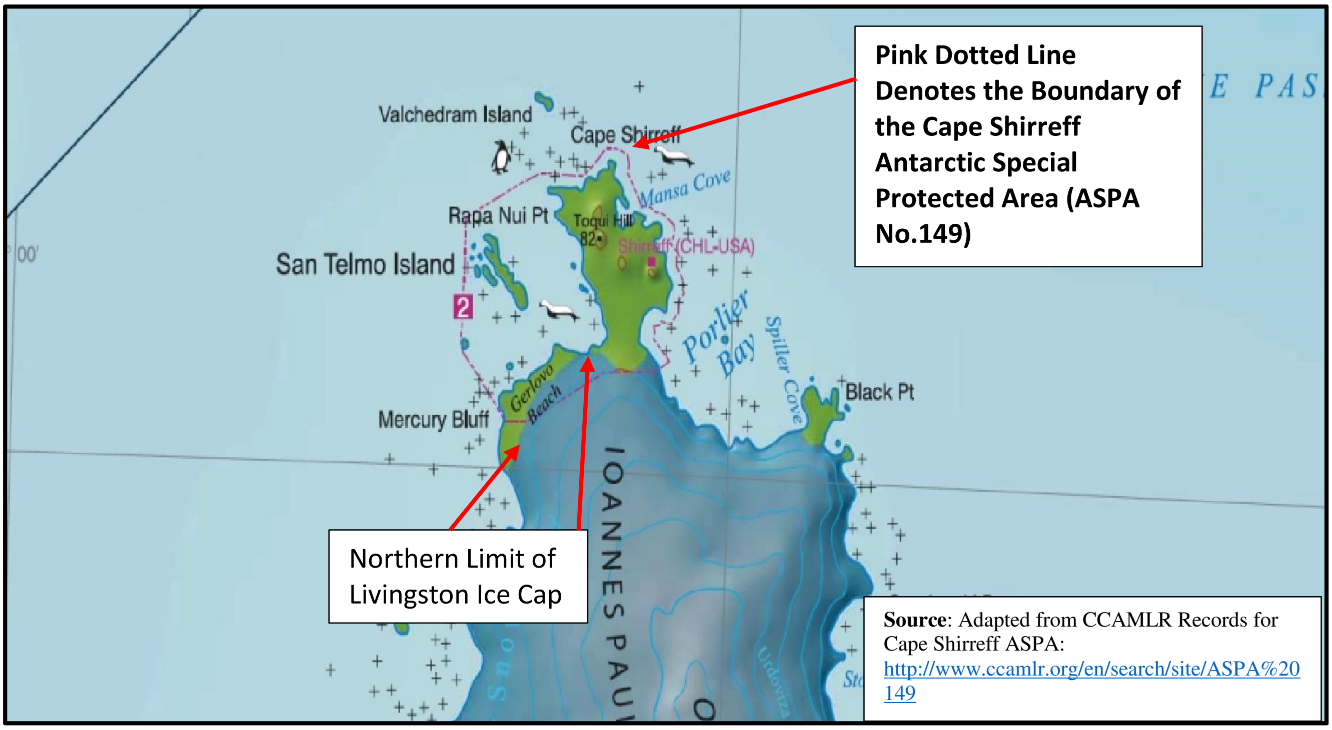
Source: Adapted from: Australian Antarctic Data Centre – Map 14029
https://www1.data.antarctica.gov.au/aadc/mapcat/display_map.cfm?map_id=14029

4.3.1 Cape Shirreff: ASPA No. 149

The Cape Shirreff Antarctic Specially Protected Area (ASPA) No. 149 (fully described as the '*Cape Shirreff and San Telmo Island, Livingston Island, South Shetland Islands*' ASPA No. 149) (Penhale & Marchant (2010)) is an area of 9.7 km^2 and located at 62°27'30"S, 60°47'17"W, and encompasses the Cape Shirreff peninsula north of the Livingston ice cap, the Sam Telmo Island group and the surrounding waters[32] (figure 4-6).

Cape Shirreff was originally designated an ASPA in 1966 due to its importance for pinniped species, in particular Antarctic fur seals (*Arctocephalus gazelle*) and southern elephant seals (*Mirounga leonina*), together with a regionally diverse array of plant and invertebrate life. Today, the designation is primarily in relation to the "*large and diverse seabird and pinniped populations*" and, of particular note to this thesis, the fact that "*Krill fishing is carried out within the foraging range of these species*" such that "*Cape Shirreff is thus a key site for ecosystem monitoring*" (Penhale & Marchant, 2010).

Figure 4-6 Cape Shirreff: Antarctic Specially Protected Area (ASPA) 149 Boundary



[32] UK FCO (2008): The Antarctic (Amendment) Regulations 2008: "*The marine boundary encloses an area that extends 100 metres from, and parallel to, the outer coastline of the Cape Sherriff peninsula and the San Telmo island group*" (p.23).

Indeed, the offshore waters surrounding Cape Shirreff are noted as being one of three areas of the highest krill biomass densities in the South Shetland Islands area, being most abundant in the nearshore area south and south-east of the Cape (Penhale & Marchant (2010), an area thought to be high in primary productivity (due to source of nutrient-rich waters from nearby submarine canyons), and highly important for the two *pygoscelid* species investigated herein.

Of particular note, is the following passage from the revised management plan "…*penguins at Cape Shirreff depend strongly upon krill for prey…Predator foraging ranges are known to overlap with areas of commercial krill fisheries and changes in the abundance of both predators and krill have been linked to climate change. Research at Cape Shirreff therefore aims to monitor krill abundance in combination with predator populations and breeding success [chinstrap and gentoo penguins], in order to assess the potential effects of commercial fishing, as well as environmental variability and climate change on the ecosystem" (ibid.,* p.11*)*

The purpose of the Cape Shirreff ASPA designation is to allow research and monitoring to continue whilst disallowing or limiting other activities which could cause harm. The most pertinent objectives of the Cape Shirreff ASPA, are:

- to avoid or minimize risk to the designation values due to human disturbance;
- to avoid activities that would interfere with monitoring activities;
- to allow scientific research of the ecosystem; and,
- to minimize the possibility of the introduction of alien plants, animals, and microbes to the area.

5.0 Research Objectives & Methodologies

This chapter provides the background to, and the design of, the research methodologies, the results and discussion of which are detailed within subsequent chapters.

5.1 Research Data Sources

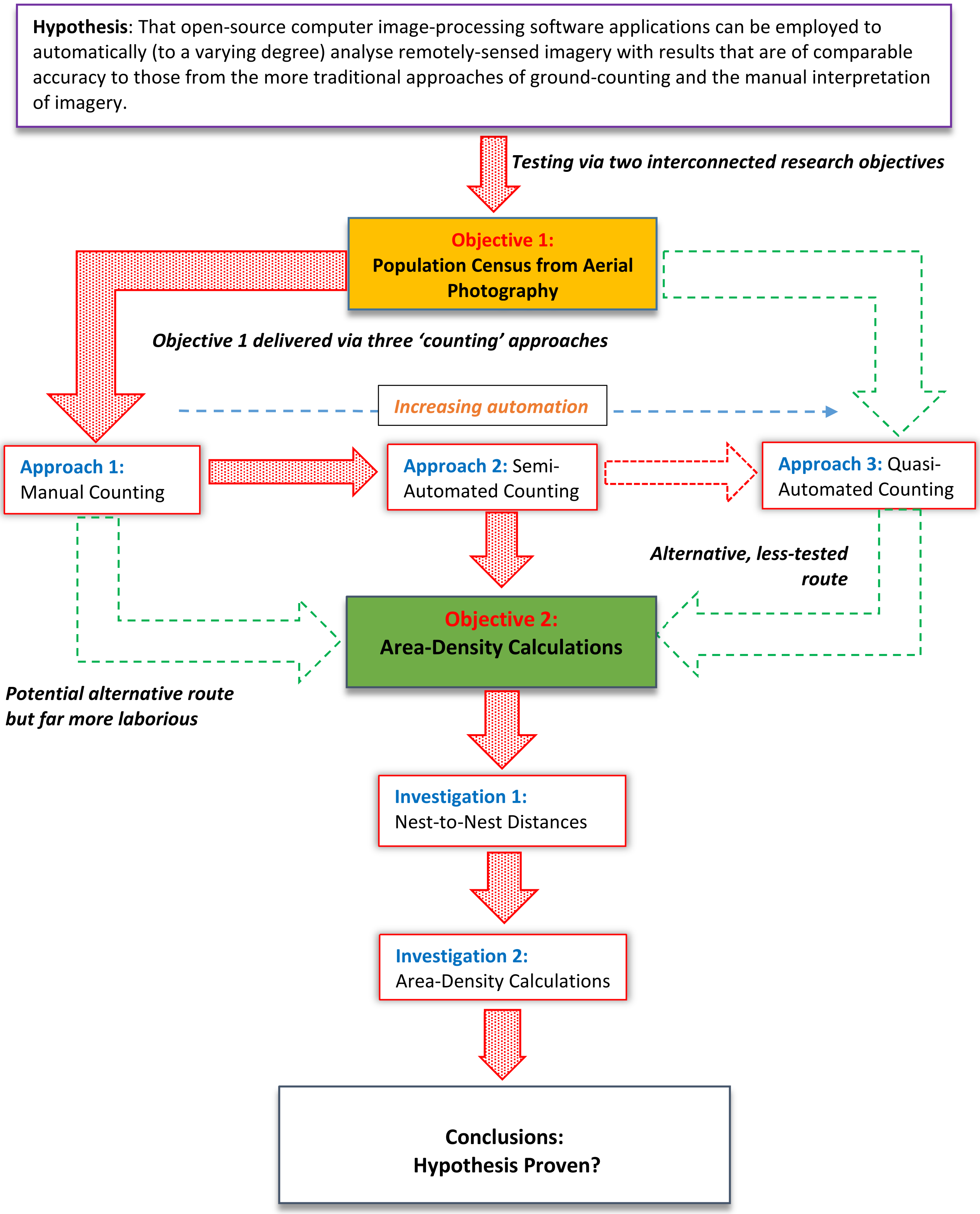
Unless otherwise stated, all aerial imagery was provided by BAS and was taken using an Intergraph DMC large format digital mapping camera mounted on a de Havilland Canada Twin Otter (DHC-6) light aircraft flown at a height of ~ 430 m (~ 1,400 ft.), and with the imagery taken on the 21st of December 2013. All colony information has been sourced from internet and publication searches, or been provided directly by BAS, other than for the (unpublished) records for the Cape Shirreff 2013-14 monitoring season which was provided by the US AMLR through BAS.

5.2 Research Design

Aside from in-situ ground-counting, the traditional approach to population census is the manual counting of 'objects' (nests, here) from imagery. This is a highly laborious process, and open to error and bias, being largely dependent on the experience or otherwise of the observer/operator (McNeill *et al.*, 2011), with such concerns generally exacerbated when applied to colonial species such as penguins given the sheer size and packing densities of some colonies, with resultant observational difficulties.

However, improvements in digital imaging devices, task-specific algorithms, and in our understanding of techniques and applications has allowed, it is contended here, such traditional counting practices to be successfully augmented using freely available, open-source, computer software. In order to test this hypothesis, two research objectives (sections 5.3 to 5.4; 5.7) were established; the first of which comprised three research methodological approaches (5.4); whilst the second incorporated two investigations (section 5.7). These research 'steps', being hierarchical in nature, are summarized in the flow diagram at figure 5-1, but in essence the three methodological approaches were designed in terms of the first research objective requirements, the results from which were used to inform the work undertaken within the second objective research.

Figure 5-1 The Research Objectives & Methodologies: Hierarchy



Note:
Red arrows indicate hierarchical methodological steps & the transfer of information between each step.
Dashed arrows signify alternative methodological approaches; as discussed here & in chapters 6 to 8.

5.3 Research Objectives

As shown above, two over-arching research objectives have been identified to test the hypothesis:

- **Objective 1**: to test the potential for remotely sensed imagery and *open-source* image processing techniques to provide accurate counts of the total number of nests within a penguin colony (referred to here as '**population census'**), when compared to the results from data collected from in-situ ground-surveys and from manually counting nests from digital imagery (section 5.4, with results detailed and discussed in chapter 6); and,
- **Objective 2**: using the results from the above to determine whether it is feasible to establish the average nest-to-nest distances for the two species; and the density of nests per square metre, from which the population of a colony (and rookery) may be extrapolated once the area of a colony is known ('**area-density'**) (section 5.7 and chapter 7).

5.4 Objective 1 (Population Census) – Research Methodologies

The research methodologies were primarily influenced by the availability of datasets, the lessons learnt from a comprehensive literature review, and an awareness of contemporary conservation priorities for the Antarctic region. They were finalised following an extensive period of methodological testing. **Three research methodologies** were developed in order to attempt to fulfil the requirements of the *first* research objective, namely:

- Approach 1: ***manual counting*** (section 5.4.1) from the imagery using traditional image analysis and counting approaches and comparison with known ground-counts from US AMLR data from the same season that the imagery was taken (2013/2014);
- Approach 2: ***semi-automated*** counting (5.4.2) combining information gathered from the first approach with computerized image processing software (ImageJ) and analysis in order to both corroborate the findings of the manual counting (given such counting is subject to human error) and, equally critical, to provide the coordinates information required for the investigations that comprised the second research objective (here, it was determined that without a need to count objects *per se*, the approach as designed allowed the observer to concentrate on the *accurate* placement of the paint markers). It is possible to gain such information during manual counting but, from extensive testing, this proved

to be far too laborious, exponentially increasing the time required to undertake the task; and,

- Approach 3: ***quasi-automated*** counting (5.4.3) utilizing ImageJ software to determine and count the number of nests within an image without pre-conceived notions of results but with operator input in terms of setting thresholds etc.

The approaches introduce an increasing degree of automation, ranging from purely observer-led observation (approach 1) to an almost entirely automated approach (approach 3). Following a large degree of experimentation and trial and error, certain steps became clear that best fulfilled the research objectives that had been set and which are reproduced at figures 5-3, 5-6, & 5-9 (whilst, attention is also drawn to appendix 2 which provides the accompanying screen-prints from each of the steps undertaken to aid future implementation).

Image Manipulation

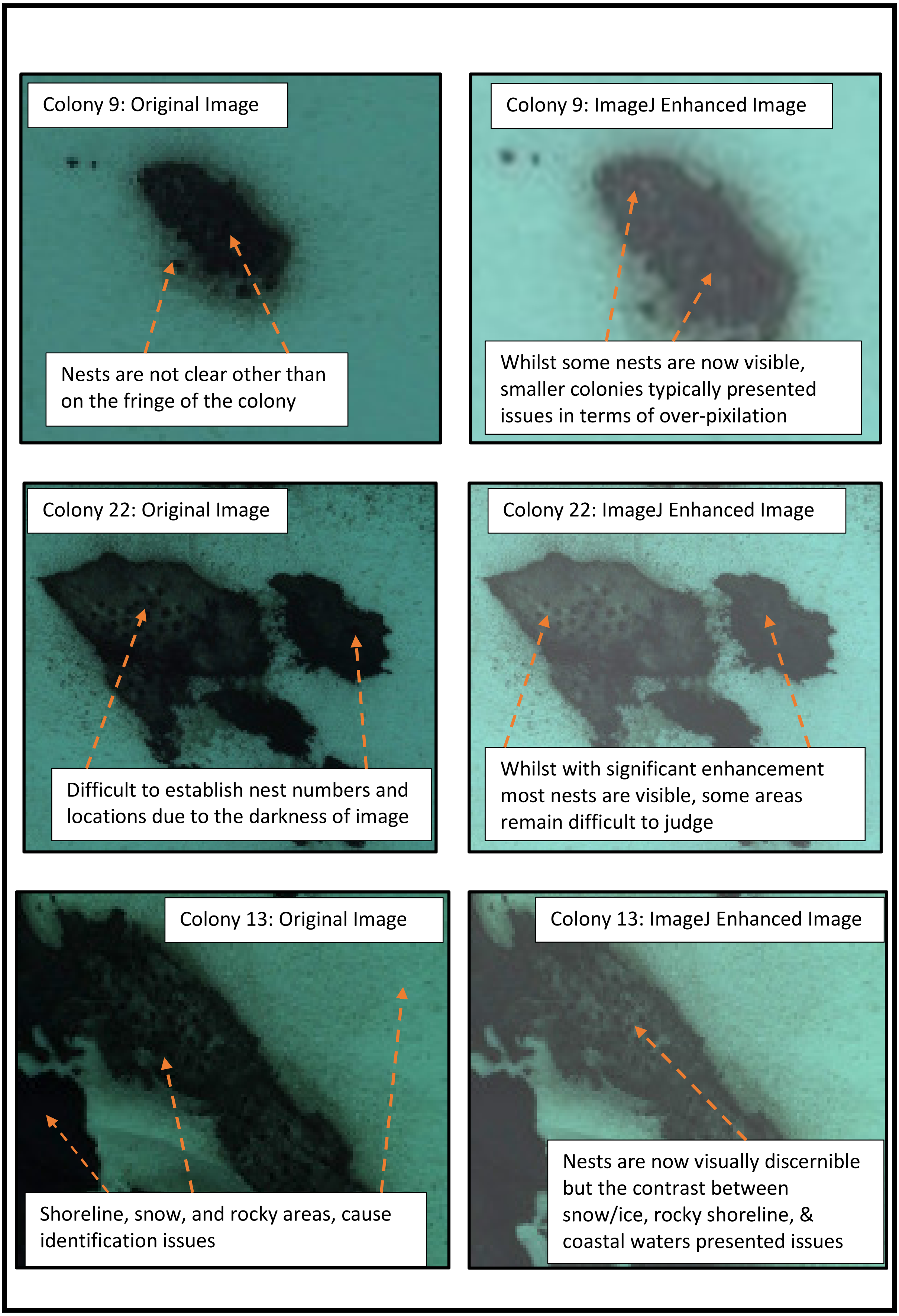
During the trialing period, it became apparent that variables such as the contrast of an image, the amount of snow and ice cover, and the differences in terrain (relief, slope) could affect the successful identification of nests. The imagery therefore required varying degrees of manipulation to optimise the chances of success. However, even with considerable image enhancement, a minority of areas remained of substandard clarity. Figure 5-2 provides examples of the issues that occasionally emerged and which are discussed in more detail in sections 5.6 & 6.2.6.

A Note on Thresholds and Particle Analysis

The step-by-step instructions detailed below are deemed to be self-explanatory and sufficiently descriptive for a novice to follow, but two particular functions within ImageJ require special consideration, namely '*thresholding*' and '*analyse particles*'.

It will be seen that the second, 'semi-automated,' approach requires the outputs from the first 'manual counting' approach. If this stage is carried out successfully, the number of identified nests *should* be identical between the two approaches. That this is not always the case is due, it is thought, to either human error in the form of a mis-count, or a slight error in the 'thresholding' of an image and with ImageJ as a consequence mis-identifying extraneous objects within an image. Such *thresholding* errors may also cause significant issues with the

Figure 5-2 Examples of Image Clarity Issues



quasi-automated approach, and are key to the use of image processing software such as ImageJ.

Thresholding essentially works by separating pixels which fall within a pre-determined (via trial and error) range of intensity values, from those which do not – with 8-bit colour and greyscale images having 256 'intensity graduations', i.e. for a greyscale image, a pixel with an intensity of 0 is black whilst 255 is white, and everything in between varying shades of grey.

Whilst each image will require slight rearrangement of the thresholds required, with practice it becomes relatively straight forward to establish the most appropriate thresholds for similar images. Coupled with thresholding is the concept of '*analyze particles*'. Analyze particles measures the objects within a thresholded image by identifying the edges of an object, outlining it, before continuing to scan the rest of the image. Thresholding in effect allows the analyze particles function to concentrate on those pixels of the correct intensity, whilst through the analyze function command, various measurements are also attainable, the most important of which for our purposes are the geographical coordinates, *x* and *y*, of a pixel (see later). For reference, for all of the images examined here, the lowest threshold value found that identified the correct nest/s was 12, and the highest 53 – i.e., all pixels with an intensity value of less than 12 or more than 53 were not, in all probability, nests.

Lastly, it should be noted that some of the steps and terminology described below are particular to the software used in the example but most software will employ similar approaches and terminology.

Structure of the Remaining Sections

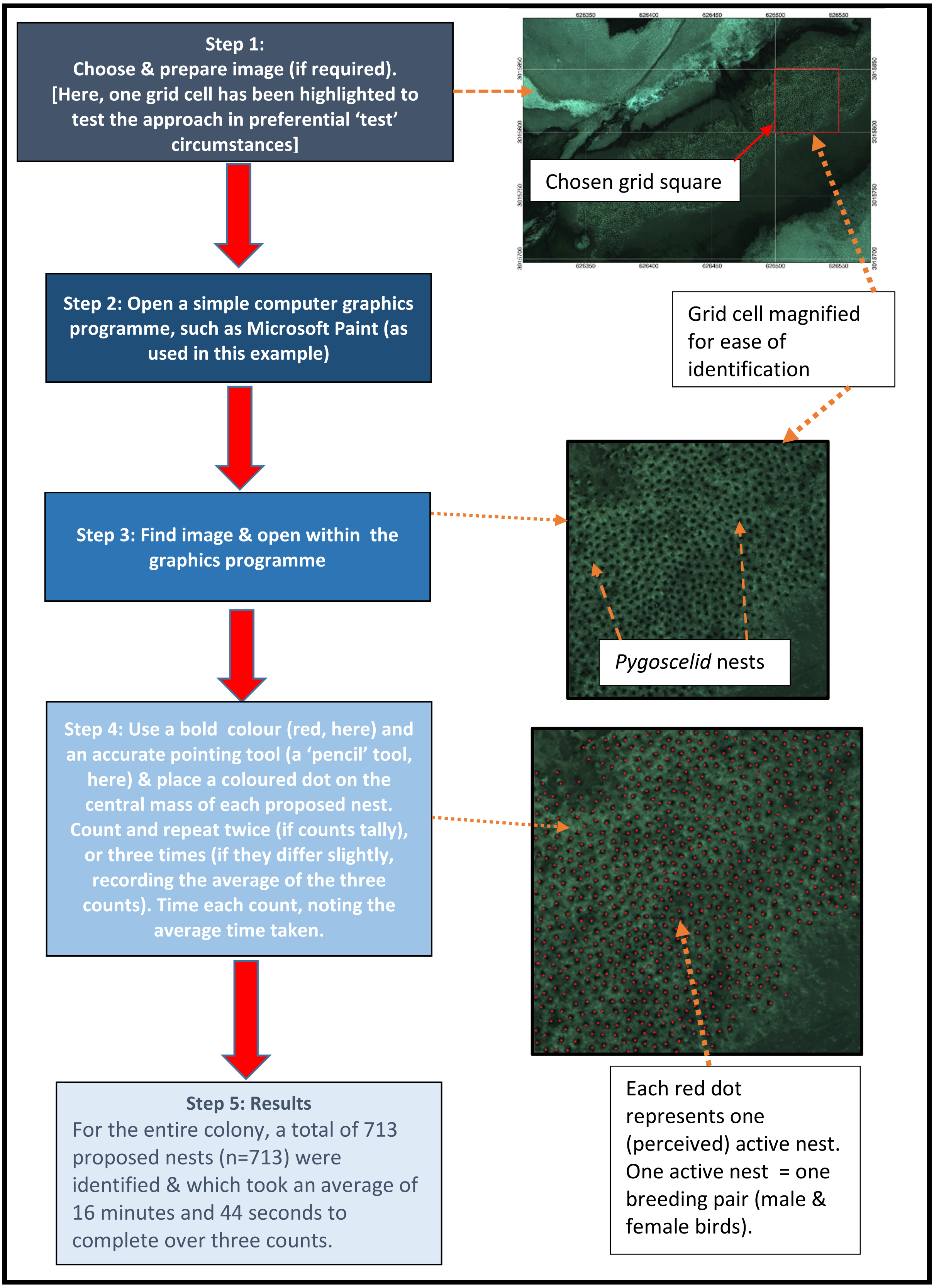
Given that this is a necessarily expansive chapter it is useful to note that sub-sections 5.4.1 to 5.4.3 proceed to detail the step-by-step processes developed in respect of the three research methodologies. These methodologies were firstly fully tested on four pilot studies (section 5.5) to allow for the identification and addressing of any issues and to test the efficacies of each approach, and which led to the need for some pre-research image manipulation (5.6). The chapter continues with a detailed description of the objective 2 (area-density) research investigations (5.7), before a final note on subsequent chapter structure (5.8).

5.4.1 Manual Counting Approach: Process & Guidance

Figure 5-3 details the steps required when adopting the manual counting approach. Appendices 2 to 4 and 6 should be consulted for additional guidance and examples.

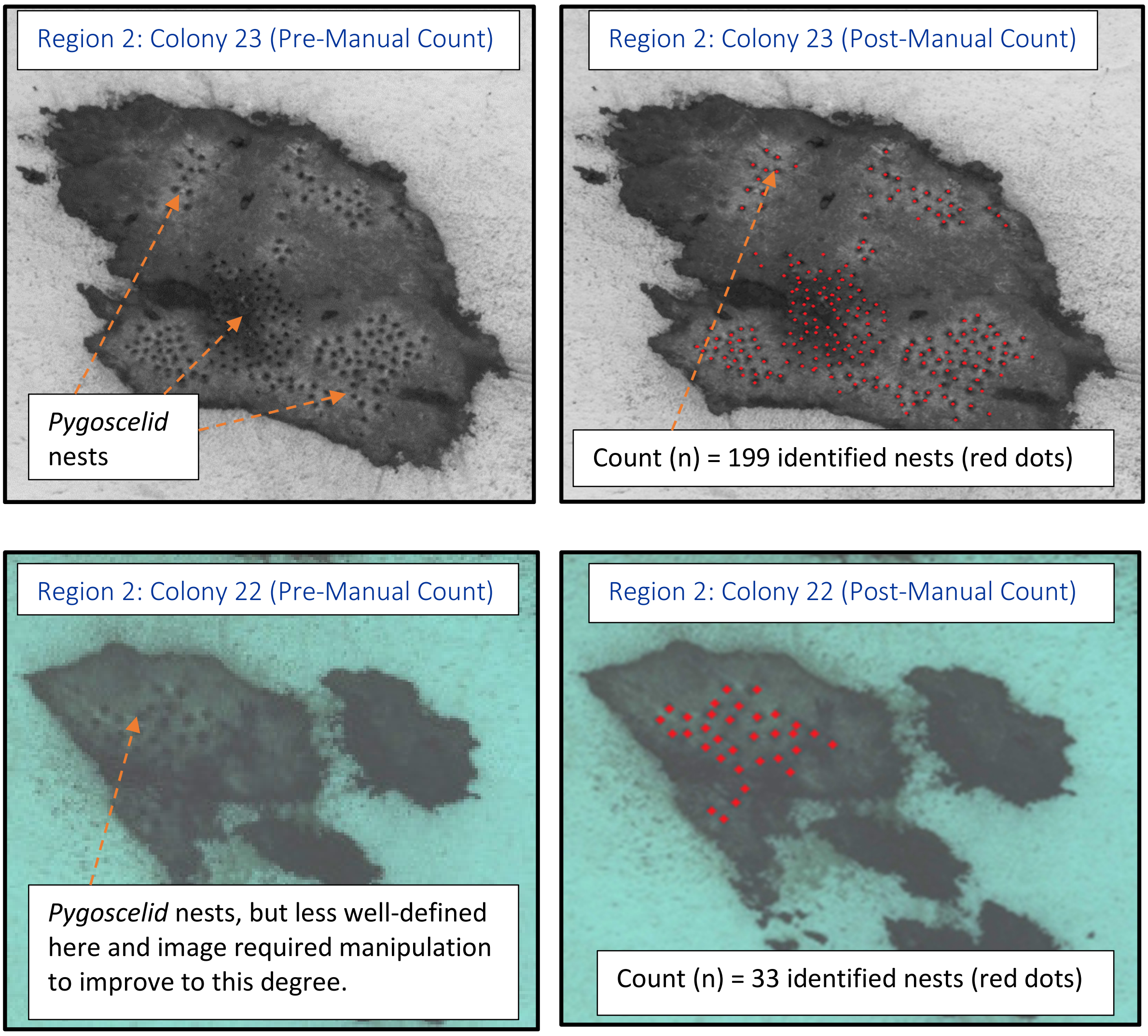
Manual counting is a plain but descriptive term for the traditional process of counting individual nests from an image without image processing. It is a necessarily laborious process which can easily result in errors, either through observer-bias (e.g. from expectations), a lack of experience, double or missed counting, or inattention. In order to address such issues, at least in part, the pilot studies (section 5.5) were used to hone skill levels and also as an aid to becoming comfortable with the use of a simple graphics programme to accurately 'dot' each nest identified with red ink, both to avoid double-counting and in the knowledge that such a means of accurate identification would be required within the second methodological approach (5.4.2) and for the objective 2 work (5.7).

Figure 5-3 Manual Counting: Step-by-Step Process



The imagery in figure 5-4, provides examples of two of the Cape Shirreff rookery colonies. In lieu of the methodological steps outlined here, the four images represent pre- and post-manual counting, with the latter providing the count tally of identified nests ('n') within the specific colony. Appendix 6 provides similar images for all of the identified colonies.

Figure 5-4 Manual Counting: Example Colony Counts



Whilst the clarity of some parts of the imagery is less than optimum, manual counting did prove possible for all of the identified colonies. For ease of analysis, it was deemed necessary to split some of the colonies into two or more component parts.

5.4.2 Semi-Automated Counting Approach: Process & Guidance

This approach was designed with two specific aims in mind: firstly, to compare the results from the manual counting exercise with those from a semi-automated counting approach, thereby also cross-verifying such results; and, secondly, to provide geographical coordinates for each nest identified, being critical information for the second research objective (section 5.7 and chapter 7). Figure 5-5 provides examples of the pre- and post-editing required of some images during the semi-automated counting process detailed in figure 5-6. Figure 5-7 provides an example of this approach once the semi-automated analysis has been completed; whilst figure 5-8 provides for a comparison of the manual counting with semi-automated counting approaches. Appendices 2 to 4 and 6 should be consulted in addition to the below.

Figure 5-5 Examples of Pre- & Post-Editing of Imagery within ImageJ during the Semi-Automated Approach Process

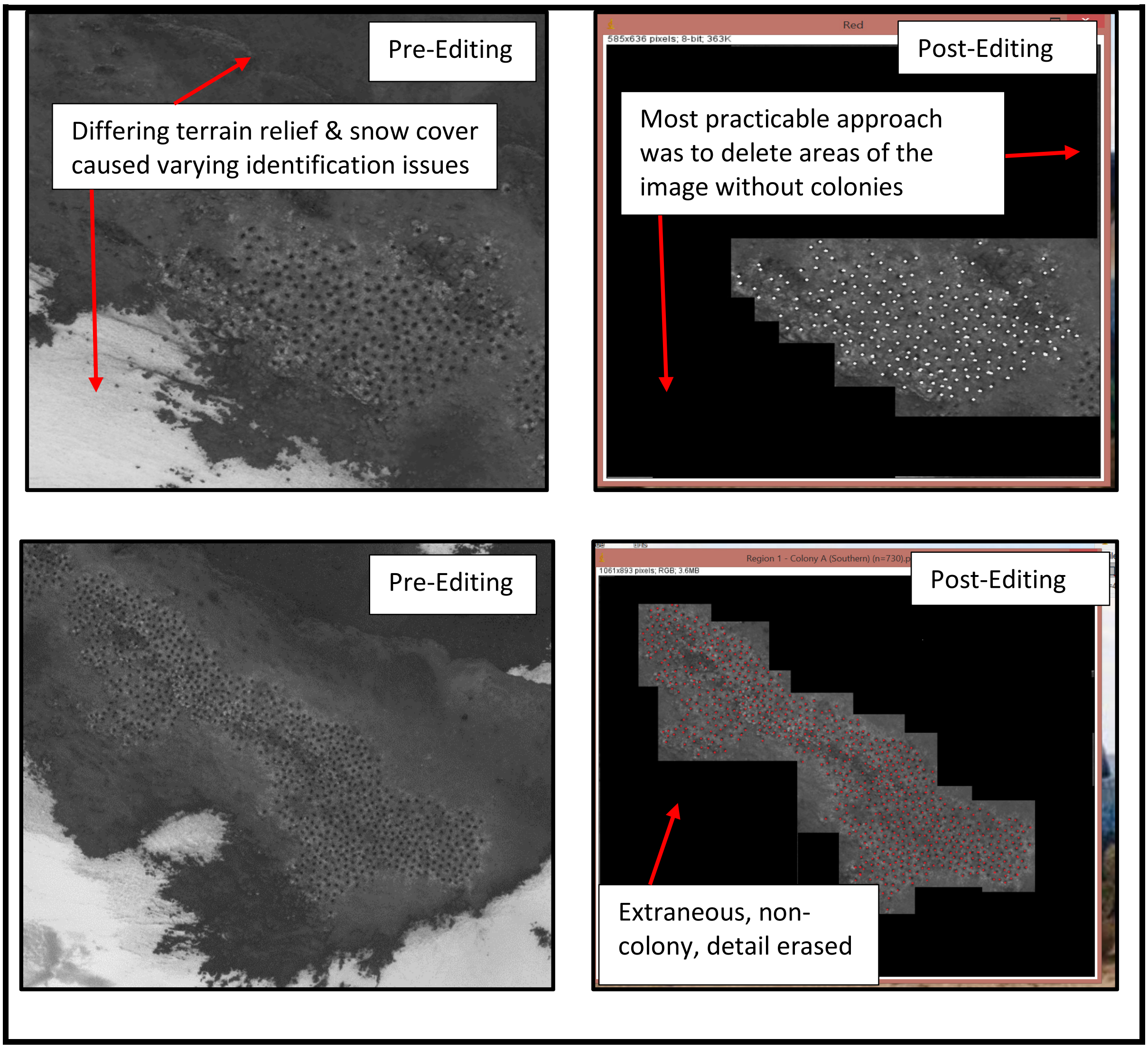


Figure 5-6 Semi-Automated Counting Approach: Step-by-Step Process

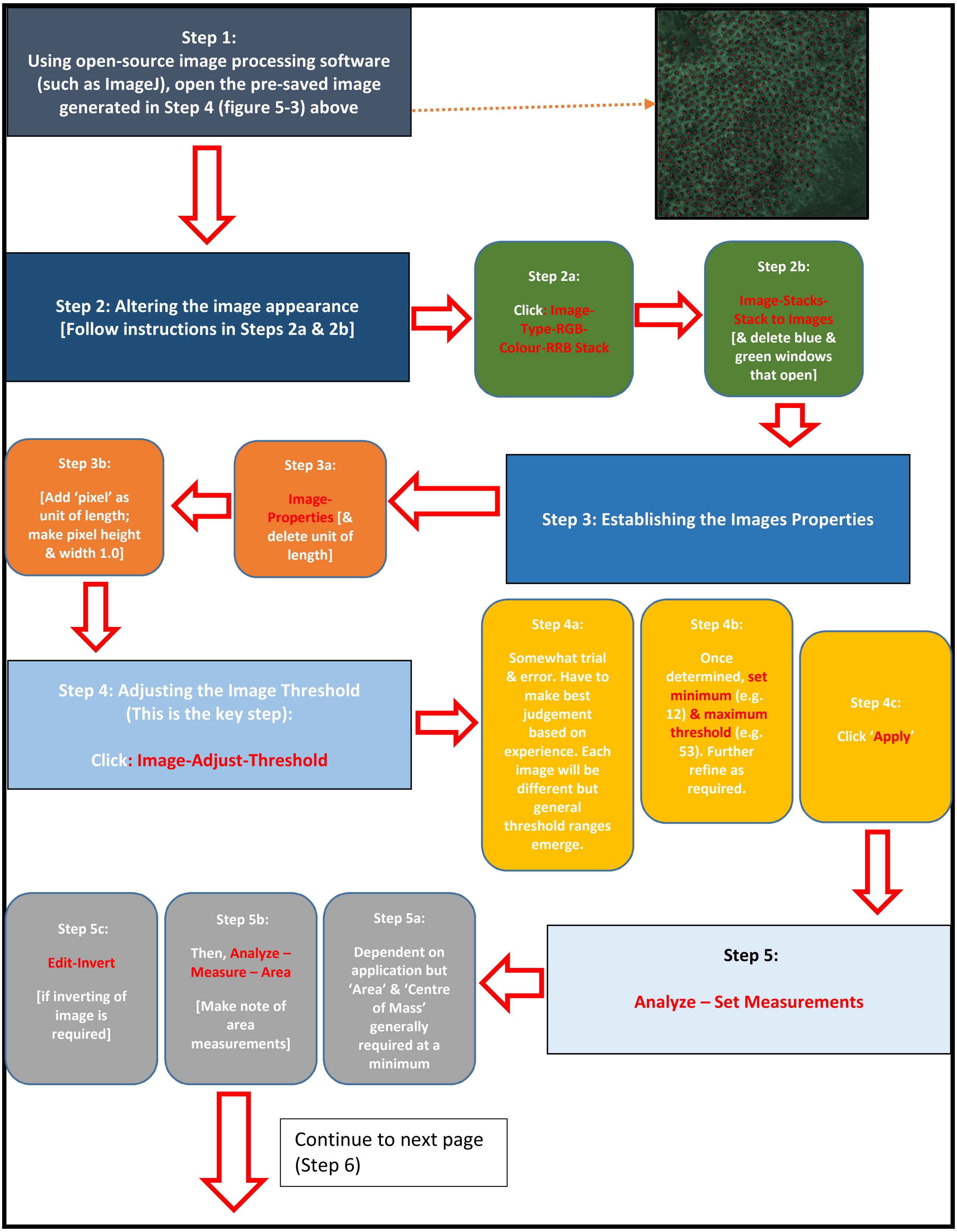


Figure 5-6 Semi-Automated Counting Approach: Step-by-Step Process (cont.)

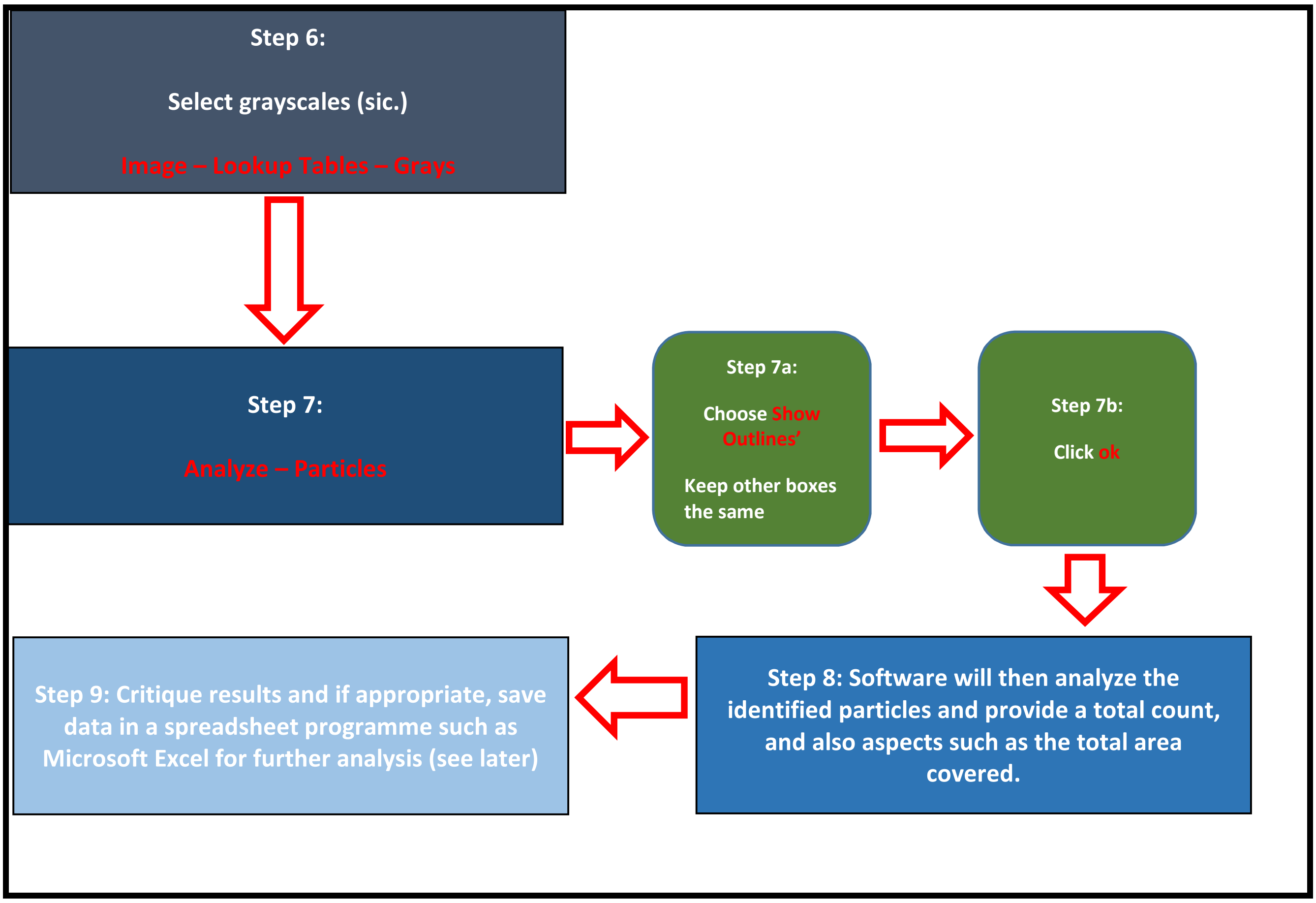
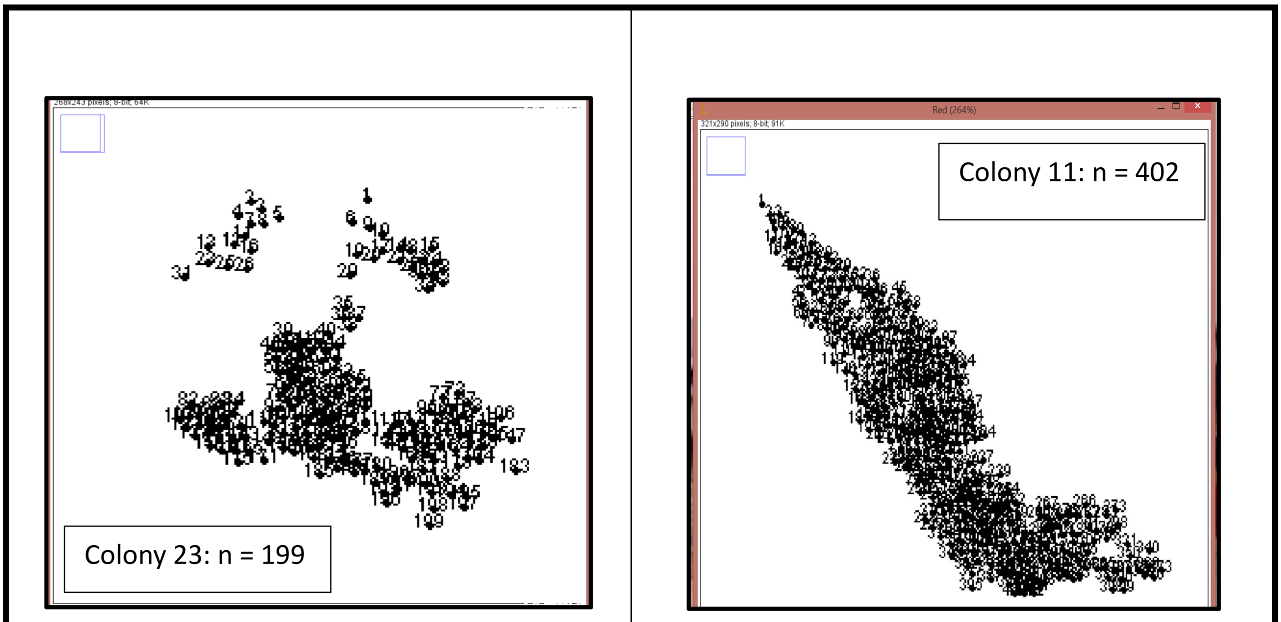
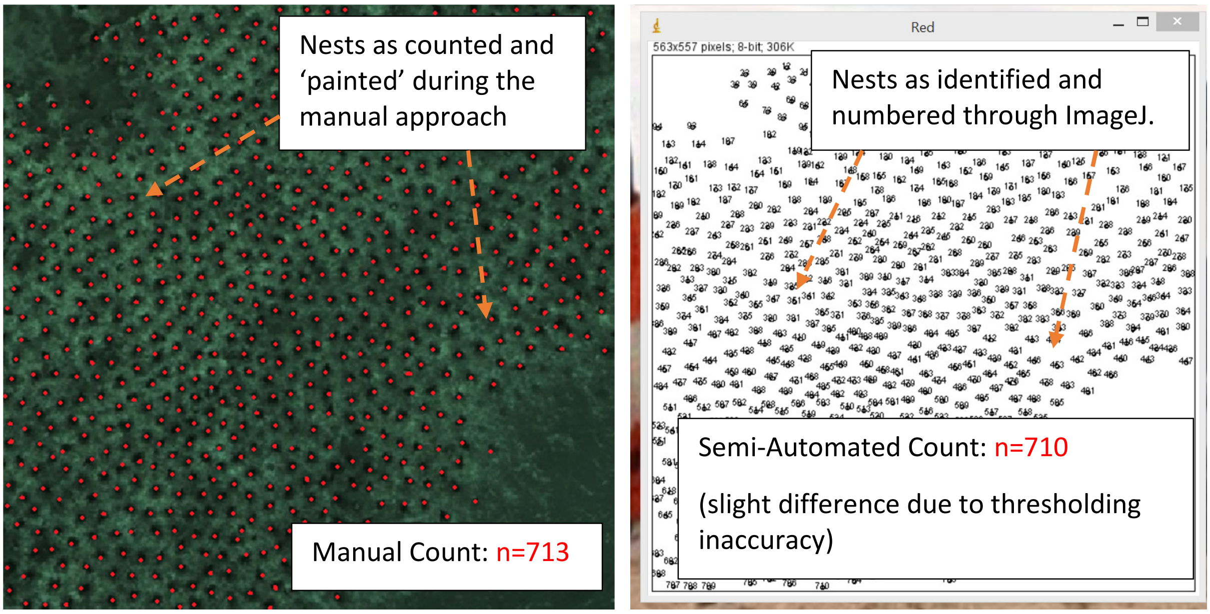


Figure 5-7 ImageJ Semi-Automated Approach - Example Outputs



The black numbers above each represent one nest identified by the semi-automated approach described earlier. See appendices 2 & 8 for further output examples.

Figure 5-8 Comparison of Manual Counting of Semi-Automated Counting Approaches



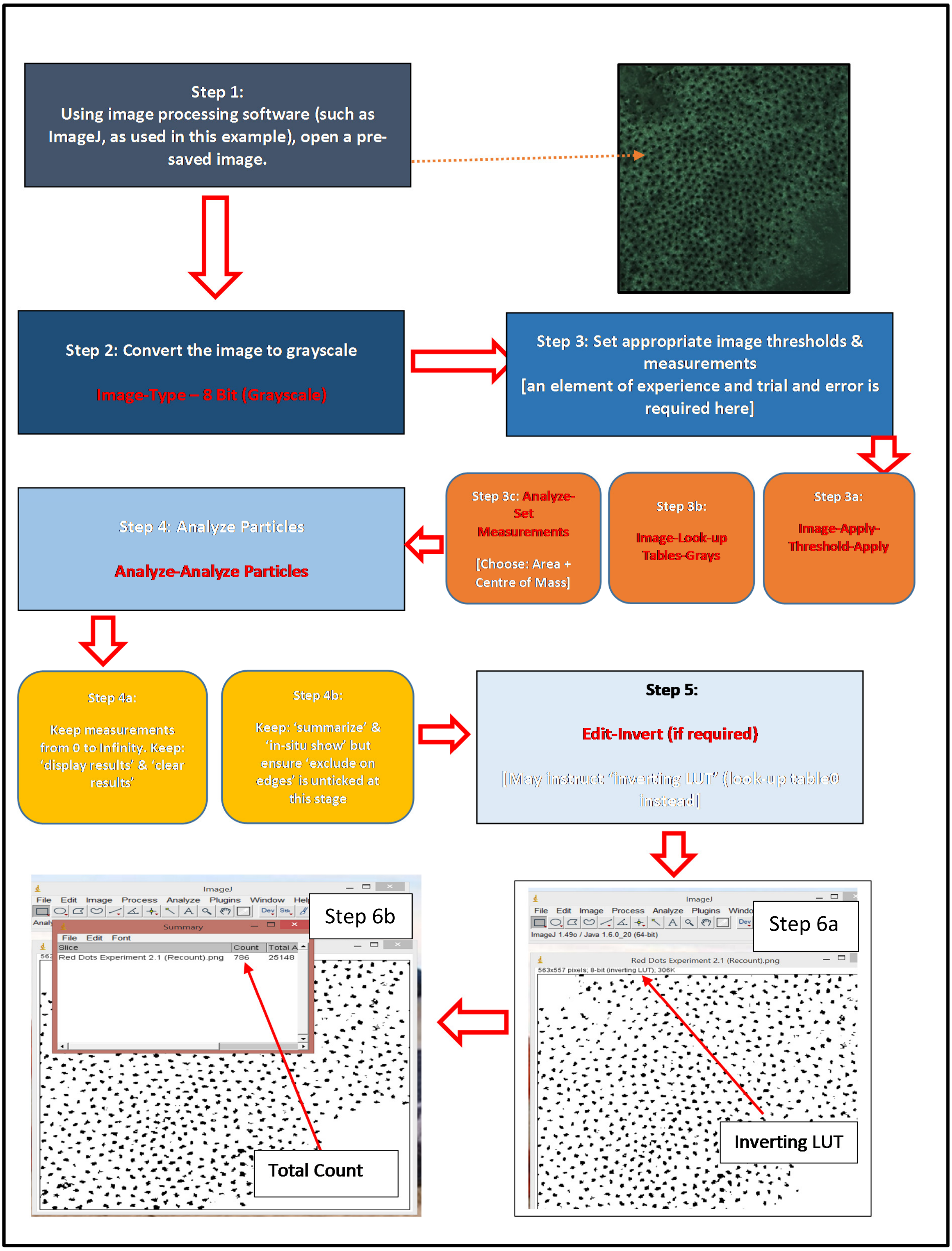
i.e. the semi-automated approach equated to an accuracy of over 99.5% when compared with the results from the manual counting within this example. Appendices 2 & 8 provide example screen prints and outputs from this approach for all of the Cape Shirreff rookery colonies.

5.4.3 Quasi-Automated Counting Approach: Process & Guidance

The quasi-automated approach incorporated the smallest degree of human input of the three approaches. Whilst the approach is similar to that of the semi-automated exercise in terms of utilising ImageJ capabilities, here, the images from which the counts were taken had not been pre-prepared or pre-counted from. Thus the images were direct facsimiles of those isolated from the parent image for each of the colonies. However, the lessons learnt from the semi-automated exercise, especially in terms of the 'disturbance' or 'interference' that might result from the topography and the environment, together with the knowledge accrued re. *expected* thresholding requirements were of course of importance. In particular, it was found that colonies 3, 10, 11, 13/14, 17, and 18 needed considerable image manipulation prior to analysis (and, similar to that shown within figure 5-5).

Figure 5-9, provides a diagram detailing the steps undertaking when using the quasi-automated approach; whilst figure 5-10 provides examples of the typical imagery generated during the process. These are further expanded on within appendix 2, whilst all results and outputs are detailed within chapter 6 and within appendix 9. Further, figure 5-11 provides output examples from all three methodological approaches discussed here.

Figure 5-9 Quasi-Automated Counting Approach: Step-by-Step Process



Export to a spreadsheet programme for further analysis.

Figure 5-10 Examples of Process Imagery during the 'Quasi-Automated' Approach Process

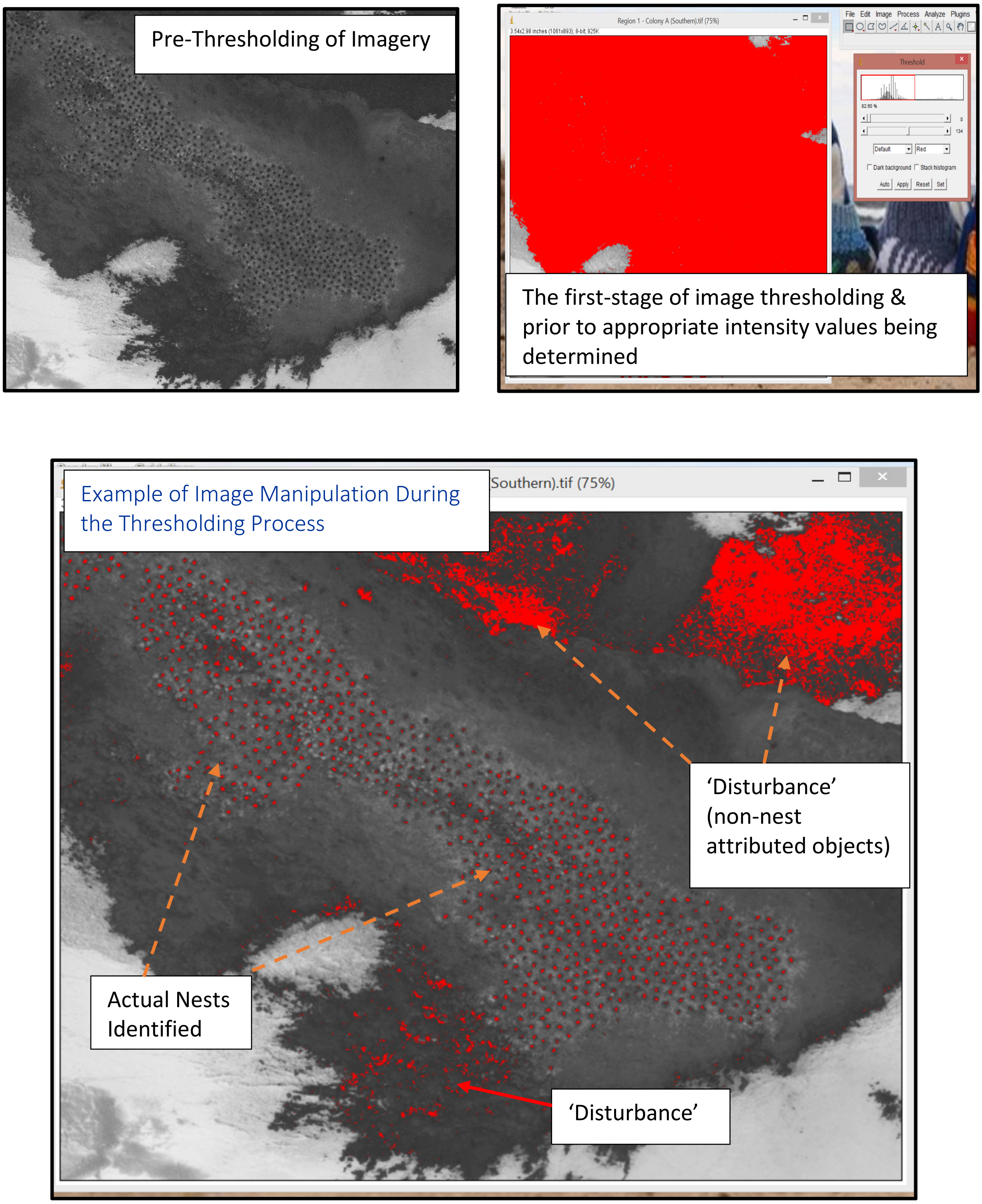
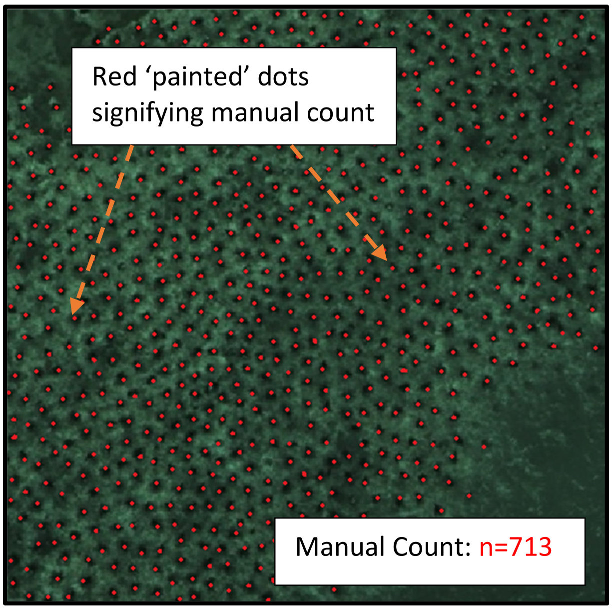
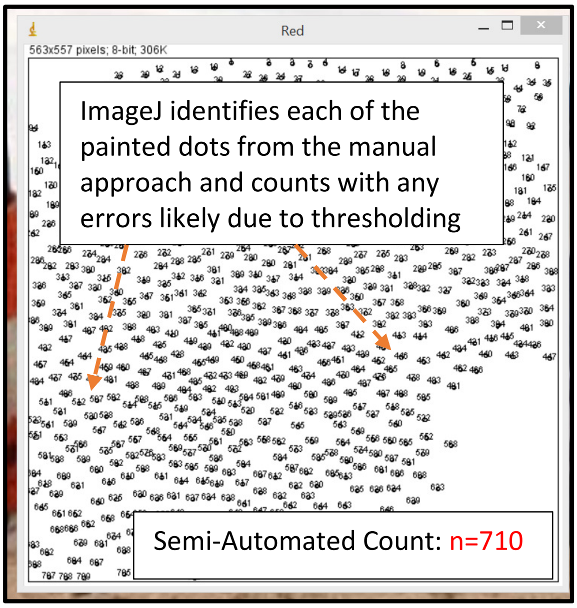


Figure 5-11 Example Results

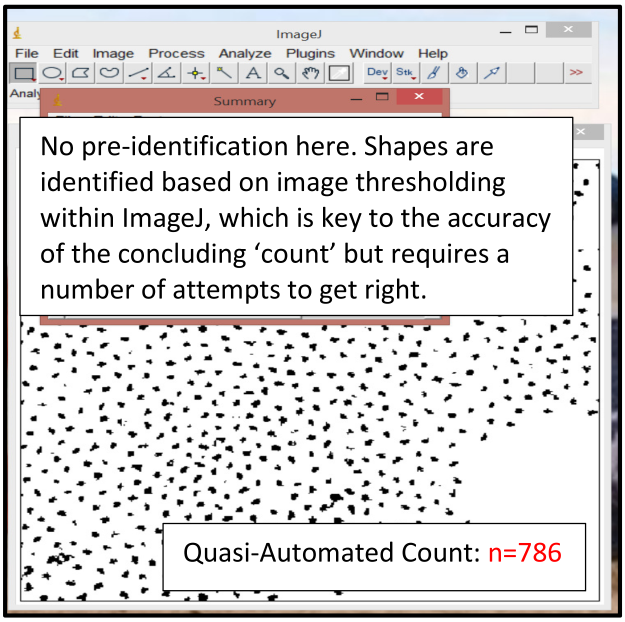
Approach 1: Manual Counting



Approach 2: Semi-Automated Counting



Approach 3: Quasi-Automated Counting



Initial Results

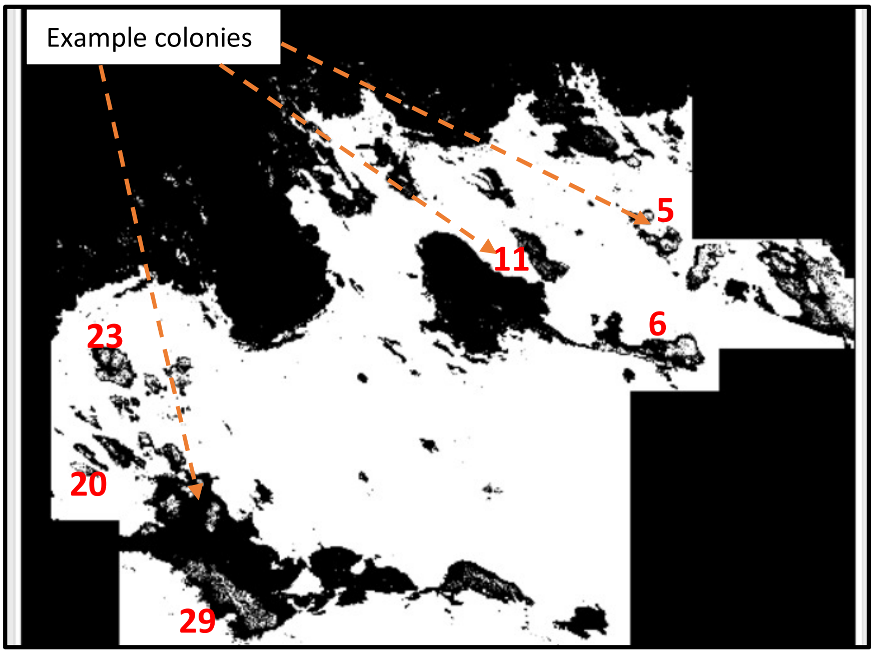
In this test example:

- the semi-automated counting compared favourably with the results from the manual counts with an accuracy of 99.58%.
- the quasi-automated counting was less accurate but still compared favourably with the manual counts with an accuracy rate of ~90%.
- Whilst some trial and error is inevitable at the beginning of the task, the approach benefits from familiarisation.

Quasi-Automated Counting for the Cape Shirreff Rookery as a Whole

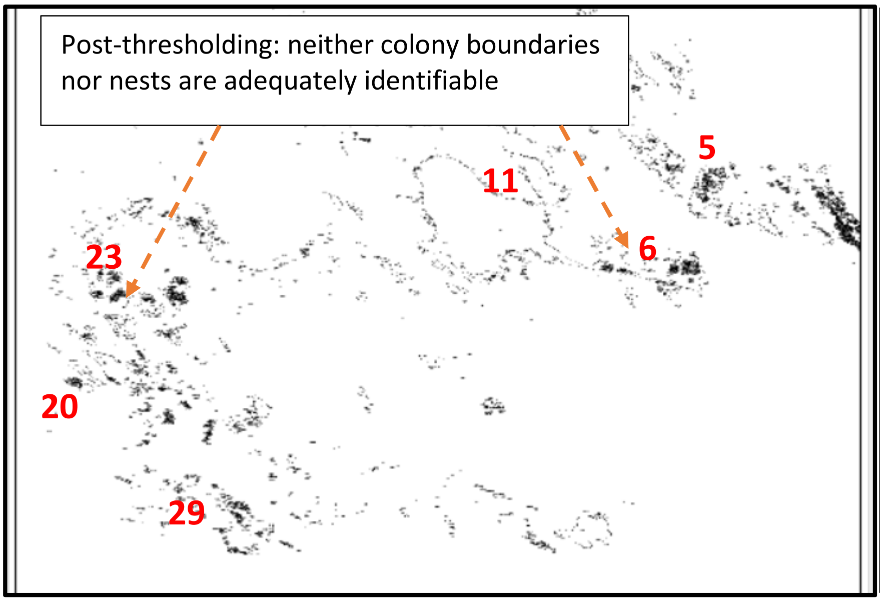
Once the above investigations had been completed, the quasi-automated approach was applied to the rookery in its entirety in *one* take to determine the veracity of this application of the methodology. Figure 5-12 is the output from this analysis, the methodology for which is as described earlier. The results are discussed further in chapter 6.

Figure 5-12 ImageJ Quasi-Automated Whole Image Analysis with Results



This image shows a reduced scale example copy of the master image when converted to 8-bit greyscale, as per the requirements of the approach (see figure 5-9, step 2).

This is the pre-thresholding stage, with the colonies still identifiable (red numbered, selected, examples).



This image is post-thresholding (figure 5-9, step 6b).

All the black parts are the objects that remain post-thresholding. They are clearly not identifying the majority of nests and the exercise has failed to allow correct thresholding limits to be set.

5.5 Objective 1 Pilot Studies

The processes detailed above were fully tested within four pilot studies in order to determine any modifications still required. Four grid squares were chosen at random from within an image provided by BAS (figure 5-13). The image was chosen in particular as whilst an image of a *Pygoscelid* colony (believe to be a colony on South Georgia), it was not one from the Cape Shirreff rookery and thus when undertaking the actual analysis of the Cape Shirreff rookery colonies there would be no possibility of operator-bias being introduced such as in terms of expected outcomes (for example with regards to expected population/s).

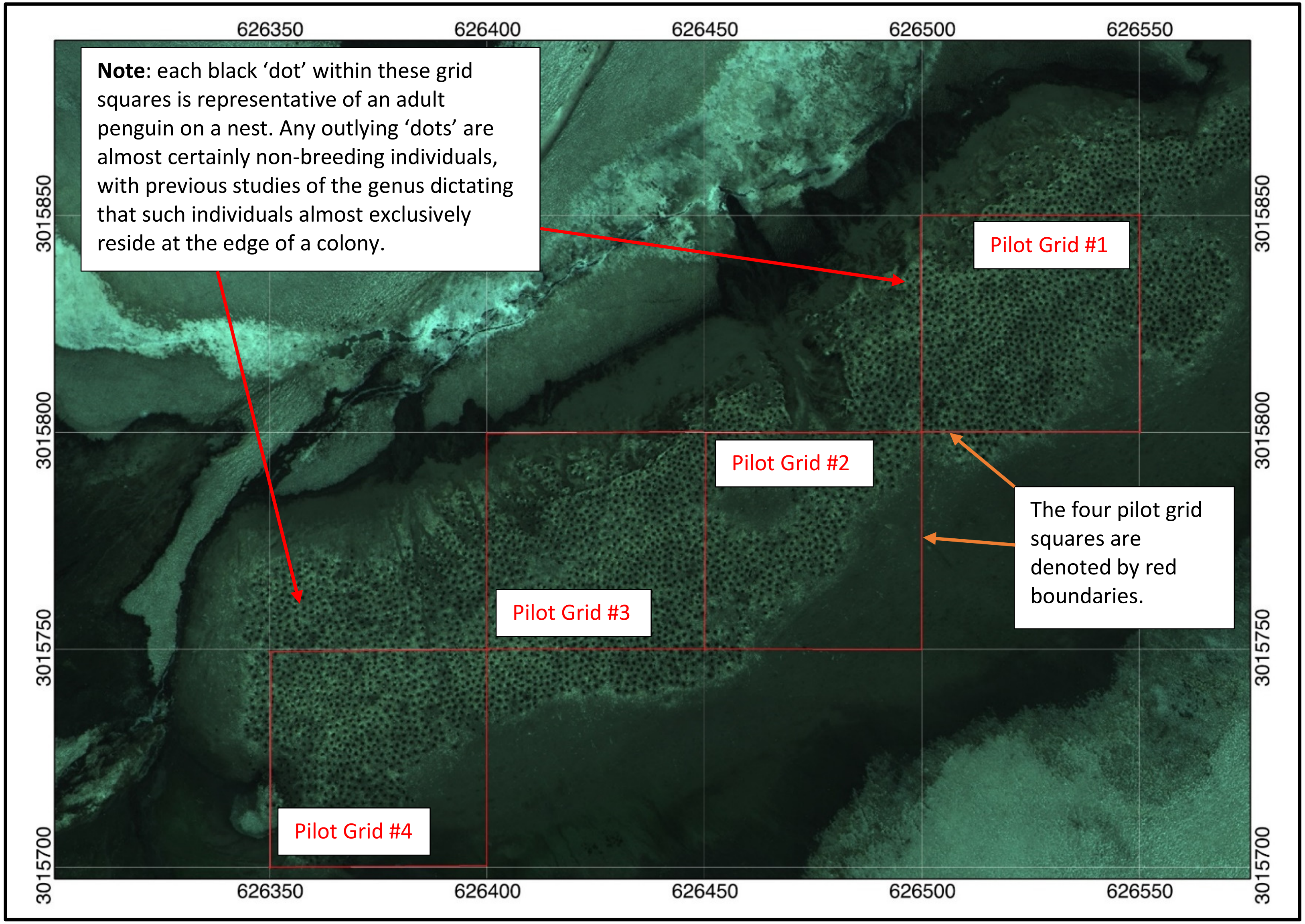
Further, the image was of sufficient spatial extent (~ 275 m x ~ 190 m, or c. 5.25 ha) to allow it to be divided into several 50 m x 50 m grid squares for ease of counting and analysis. One of the lessons learnt during the course of the preparatory work was that placing a defined grid lattice onto an image aided the manual counting process in early attempts, both in terms of providing ease of reference and in terms of illustrating the progress being made by the observer, but that with practice this became unnecessary. Lastly, the image contained areas of contrasting clarity, thus providing degrees of difficulties in terms of identification and counting.

Table 5-1 provides the results from the three counting approaches undertaken for the four pilot studies; whilst figure 5-14 provides an example of the test outputs from one pilot study and which are also reproduced in full for each of the four pilot studies within appendix 3.0.

Table 5-1 Compilation of Counting Results from the Four Pilot Studies

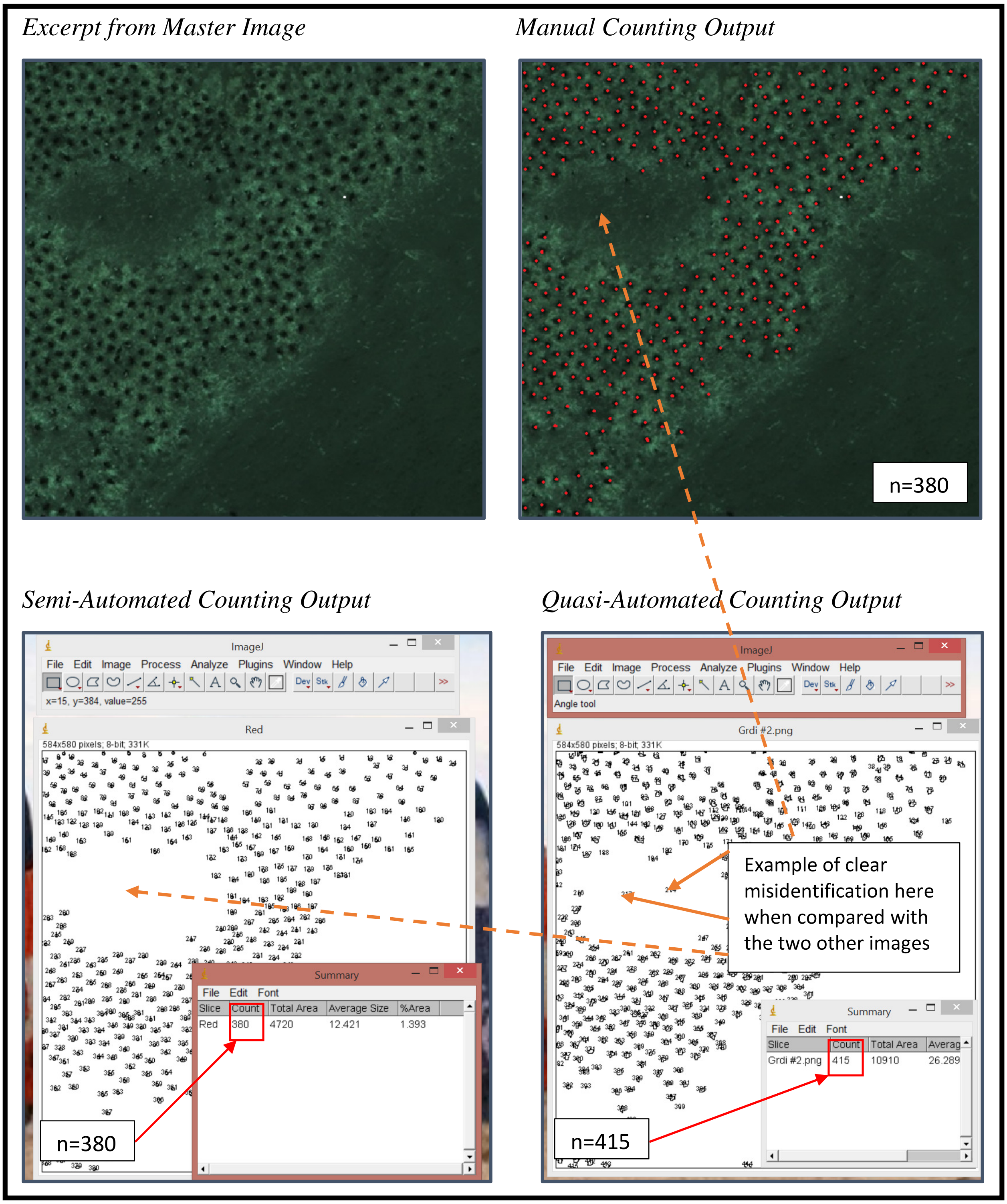
Test Grid	Manual Counting	Semi-Automated Counting	% Accuracy Compared to Manual Counting	Quasi-Automated Counting	% Accuracy Compared to Manual Counting
	Number (No.) of Nests Found			**No. of Nests**	
Test Grid #1	713	710	99.58%	786	90.71%
Test Grid #2	380	380	100.00%	415	91.57%
Test Grid #3	736	737	99.86%	742	99.33%
Test Grid #4	585	586	99.83%	619	94.51%
Totals (Nests)	**2,414**	**2,413**		**2,562**	
Accuracy Compared to Manual Counting			**99.82%**		**94.03%**

Figure 5-13 Location of the Four Pilot Studies



Whilst it was not surprising that the semi-automated counting provided for results that were nearly identical (99.82%) (table 5-1) to those from the manual count, the results of the quasi-automated counting (at 94.03% accurate when compared with the manual counting), were sufficiently encouraging to proceed to adopt the approaches for the actual Cape Shirreff rookery imagery.

Figure 5-14 Pilot Study #2 Grid Square: Outputs from the Three Counting Approaches



5.6 Cape Shirreff Imagery: Preparatory Work

Unlike the imagery used for the four pilot studies, the aerial photography provided for the Cape Shirreff rookery from which the research methodologies were tested, required extensive preparation before testing could begin within the software packages being utilised.

The 'parent' or 'master' image (i.e. the image as received from BAS and prior to any enhancement, see figure 5-15) was both extensive in spatial scale (~1.26 km^2) and incorporated a DEM which allowed the image to be ortho-rectified to compensate for any distortion due to uneven terrain, whilst also being fully geo-referenced. This resulted in an image of approximately 3.45 gigabytes in file-size, far too large to be easily handled and manipulated by ImageJ in particular, at least when restricted to using 'normal' computer processing power. Further, the image was found to be very dark in many areas which would have prevented the ImageJ software from being able to identify many of the *Pygoscelid* nests within the image without modification.

It was decided, therefore, that the image would firstly need editing. Further, on closer (and lengthy) inspection of the image from within a free, open-source, Geographical Information System (GIS) software application (QGIS[33], version 2.4) and through an image-viewing software platform (Microsoft Photo Viewer), it became clear that all of the *Pygoscelid* colonies within the Cape Shirreff rookery were to be found within *two* geographic regions (depicted as Region 1, colonies to the east of the image, and Region 2, colonies to the west of the image), within the same general area (to the north-north-east quadrant of the image), as shown in figures 5-16 and 5-17; a determination that was later corroborated by the findings detailed within US AMLR's ASPA management plan for Cape Shirreff (Penhale & Marchant, 2010, Map 3 '*Breeding colonies and human features*').

With this in mind, the image was manipulated within a further open-source software application, MultiSpec© (version 3.4[34]). MultiSpec is an image-analysis tool that may be seen as complementary to ImageJ. Whilst it lacks some functionality in terms of aerial photographic imagery manipulation in comparison, being chiefly employed in the analysis of satellite imagery, it does *critically* have geo-referencing capabilities which ImageJ does not.

[33] QGIS: a cross-platform, open-source GIS software application: http://www.qgis.org/en/site/

[34] https://engineering.purdue.edu/~biehl/MultiSpec/

Once the above modifications were completed, two images (figures 5-18 and 5-19) were constructed representing the two geographical locations within the Cape Shirreff rookery that contained the colonies, whilst dispensing with the remaining areas of the image. These two images were far smaller in file-size and were therefore able to be more easily opened and manipulated, including in terms of significantly altering the brightness and contrast of the imagery which substantially addressed the concerns of the darkness of the parent imagery. Whilst this did result in an element of 'over-exposure' for some areas, this was deemed to not be of concern for the matter in hand. Appendix 10 provides close up images and aligned information for all of the colonies.

Following this early-stage analysis, locational data was received for the colonies from the US AMLR, via BAS[35]. This provided latitudinal and longitudinal coordinates for the majority of the colonies and which was imported into QGIS in order to locate the colonies within the wider Cape Shirreff rookery. Unfortunately, not all of the colonies were represented and whilst the colonies within Region 1 (Eastern) were relatively easy to identify and locate, the majority of the colonies within Region 2 (Western) required a far greater degree of investigation but all were, eventually, located.

The rookery contains nineteen (19) colonies in total, some of which comprise two or more composite areas (noted as 'A', 'B', etc., where required). However, it is important to note that Colony 2 is defined by the US AMLR as a 'non-disturbance' colony. There are no attributable details for the colony other than providing coordinates that suggest an inshore waters location (presumably to protect the actual location). The noted field count for the colony is 291 nests. As I was not able to complete an analysis of this 'protected' site, it was removed from the calculations and will not be referred to again unless appropriate.

For consistency, I kept with the nomenclature used by the US AMLR, as noted in table 5-2 (with positional coordinates and species composition):

[35] *Pers. Comm.* via email from Dr. P. Trathan (BAS) (April 23rd, 2014), relaying information from Dr. J. Hinke, at the US AMLR.

Table 5-2 Colony Nomenclature, Composition, & Coordinates

Colony Number	Region	Species Present	Latitude [a]	Longitude
3	East	Congeneric [b] colony	-62.4609 -62.4607	-60.7873 -60.7885
5	East	Congeneric colony	-62.4607	-60.7897
6	East	*P. papua* (gentoo)	-62.4610	-60.7897
8	East	Congeneric colony	-62.4603	-60.7904
9	East	*P. antarctica* (chinstrap)	-62.4602	-60.7910
10	East	Congeneric colony	-62.4596 -62.4595 -62.4593	-60.7911 -60.7916 -60.7909
11	East	*P. antarctica* (chinstrap)	-62.4604	-60.7918
12	East	*P. antarctica* (chinstrap)	-62.4601	-60.7922
13	East	*P. antarctica* (chinstrap)	-62.4601	-60.7945
14	East	*P. antarctica* (chinstrap)	-62.4601	-60.7949
17	West	*P. papua* (gentoo)	Not included	
18	West	*P. papua* (gentoo)	-62.4615 -62.4617	-60.7973 -60.7969
20	West	Congeneric colony	-62.4612	-60.7983
21	West	*P. papua* (gentoo)	-62.4616	-60.7981
22		*P. papua* (gentoo)	-62.4613	-60.7976
23	West	Congeneric colony	-62.4610	-60.7980
24	West	*P. papua* (gentoo)	-62.4610	-60.7969
27	West	*P. antarctica* (chinstrap)	-62.4621	-60.7985
29	West	*P. antarctica* (chinstrap)	-62.4623 -62.4624	-60.7967 -60.7958

Notes:
[a] Larger colonies have multiple coordinates to clarify the extent of the colony.
[b] Congeneric colonies have both species present: *P. antarctica* (chinstrap) & *P. papua* (gentoo).
2 Orange numbers signify the presence of *P. antarctica* (chinstrap), only.
6 Green numbers signify the presence of *P. papua* (gentoo), only.
3 Red numbers signify congeneric colonies.

The colony nomenclature is thus:

- *Region 1* (Eastern – accounting for ten colonies): Colony 3 (comprising areas A + B); Colony 5; Colony 6; Colony 8; Colony 9; Colony 10 (A + B + C); Colony 11; Colony 12; Colonies 13 + 14 (which are combined, here, as they are not individually separable); and,
- *Region 2* (Western – accounting for nine colonies): Colony 17; Colony 18; Colony 20; Colony 21; Colony 22; Colony 23; Colony 24; Colony 27; and Colony 29.

Of the 19 colonies, 6 are congeneric (contain both species); 7 contain chinstraps only; whilst, the remaining 6 colonies are exclusively gentoo territory.

Note, that the colonies are not sequentially numbered, presumably as the intervening numbers have been used for either failed or historically extinct colonies and/or non-*Spheniscidae* colonies or species assemblages.

Figure 5-15 MultiSpec© Snapshot of Cape Shirreff Parent (Original) Imagery – with Approximate Delineation of the Region where *Pygoscelid* Colonies are Located

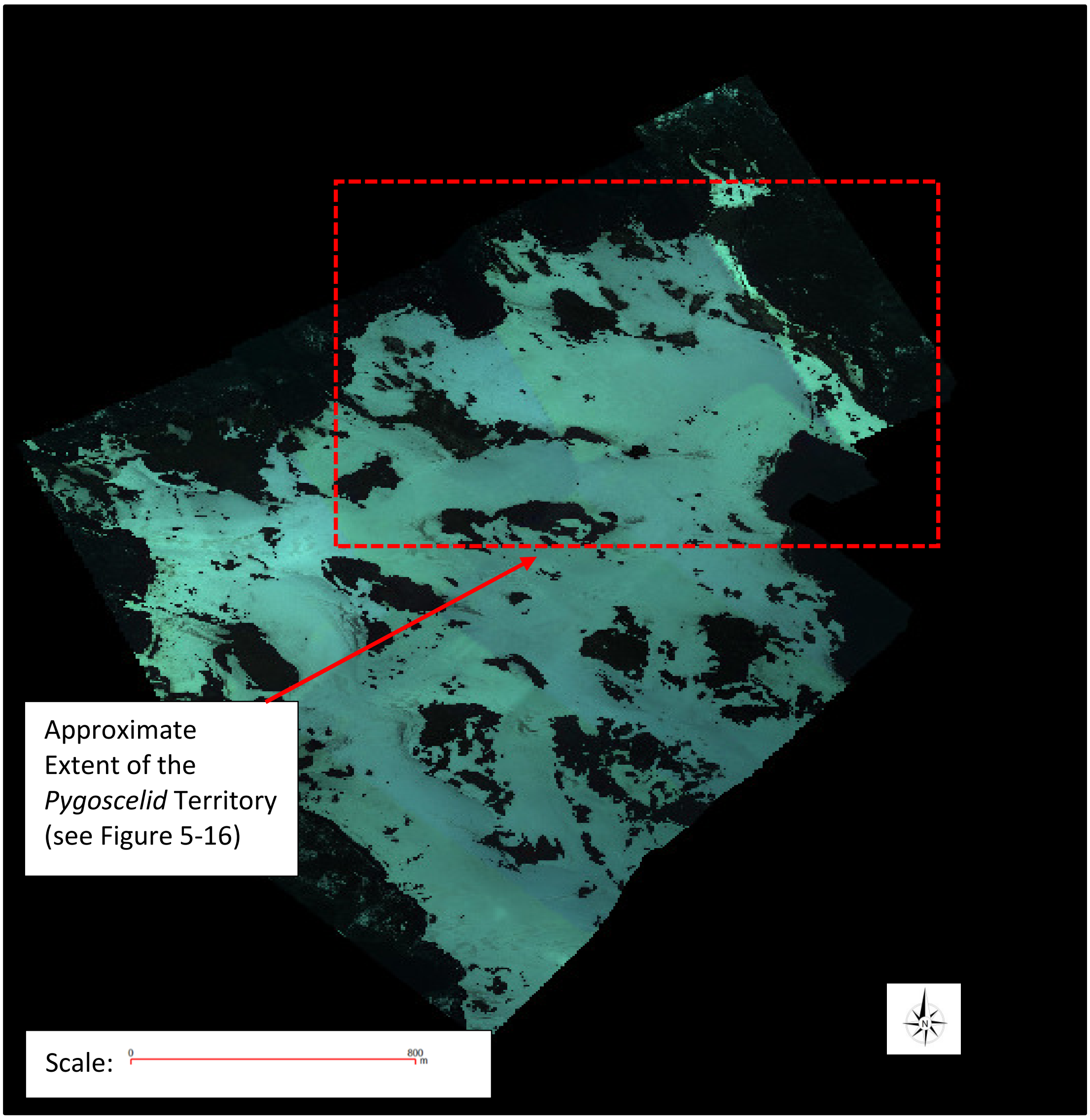


Figure 5-16 Truncated & Expanded Parent Image of *Pygoscelid* Territories within Cape Shirreff

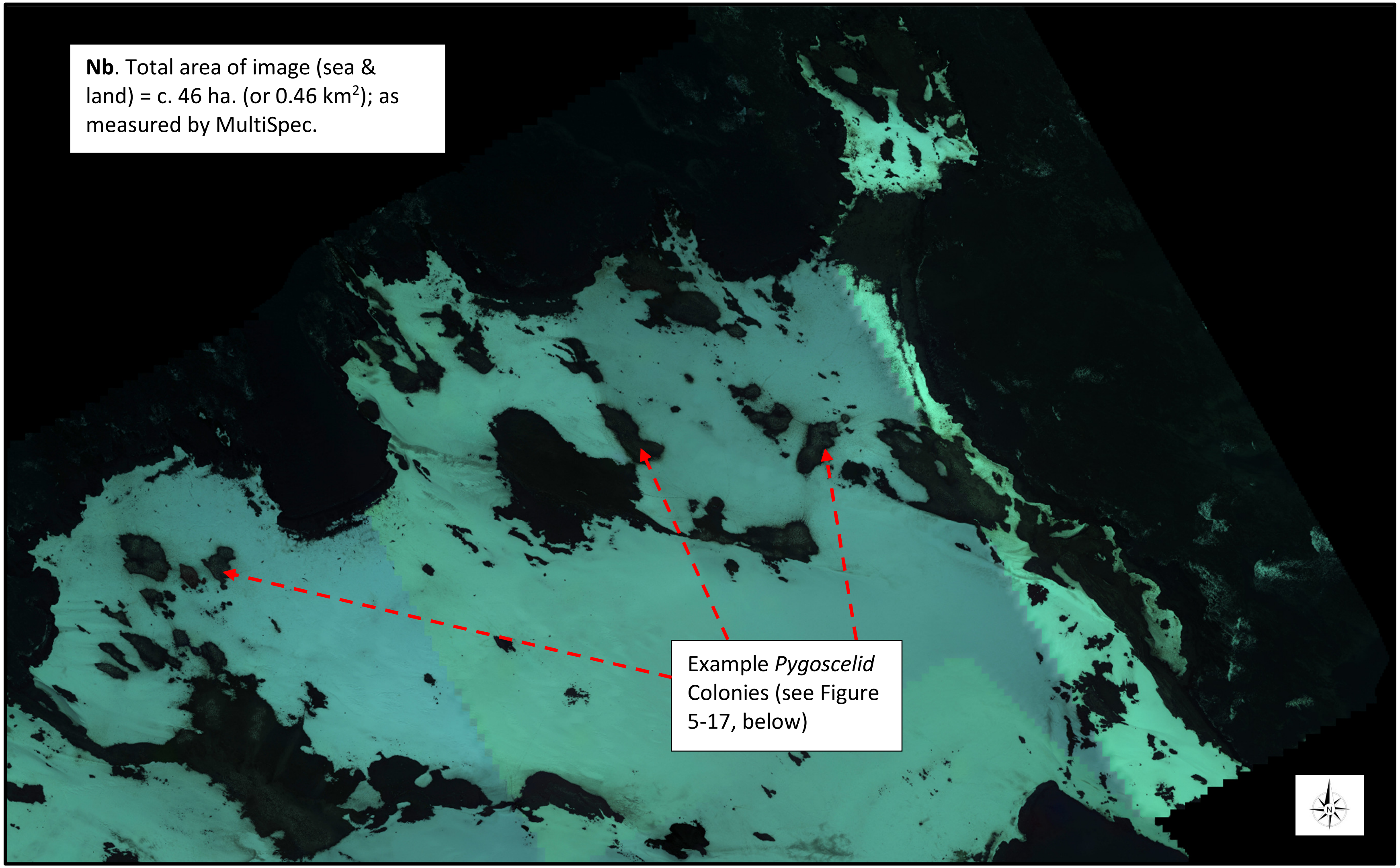


Figure 5-17 Approximate Location of *Pygoscelid* Colonies (Orange & Red Boundaries) within the Two Defined Regions of the Cape Shirreff Rookery

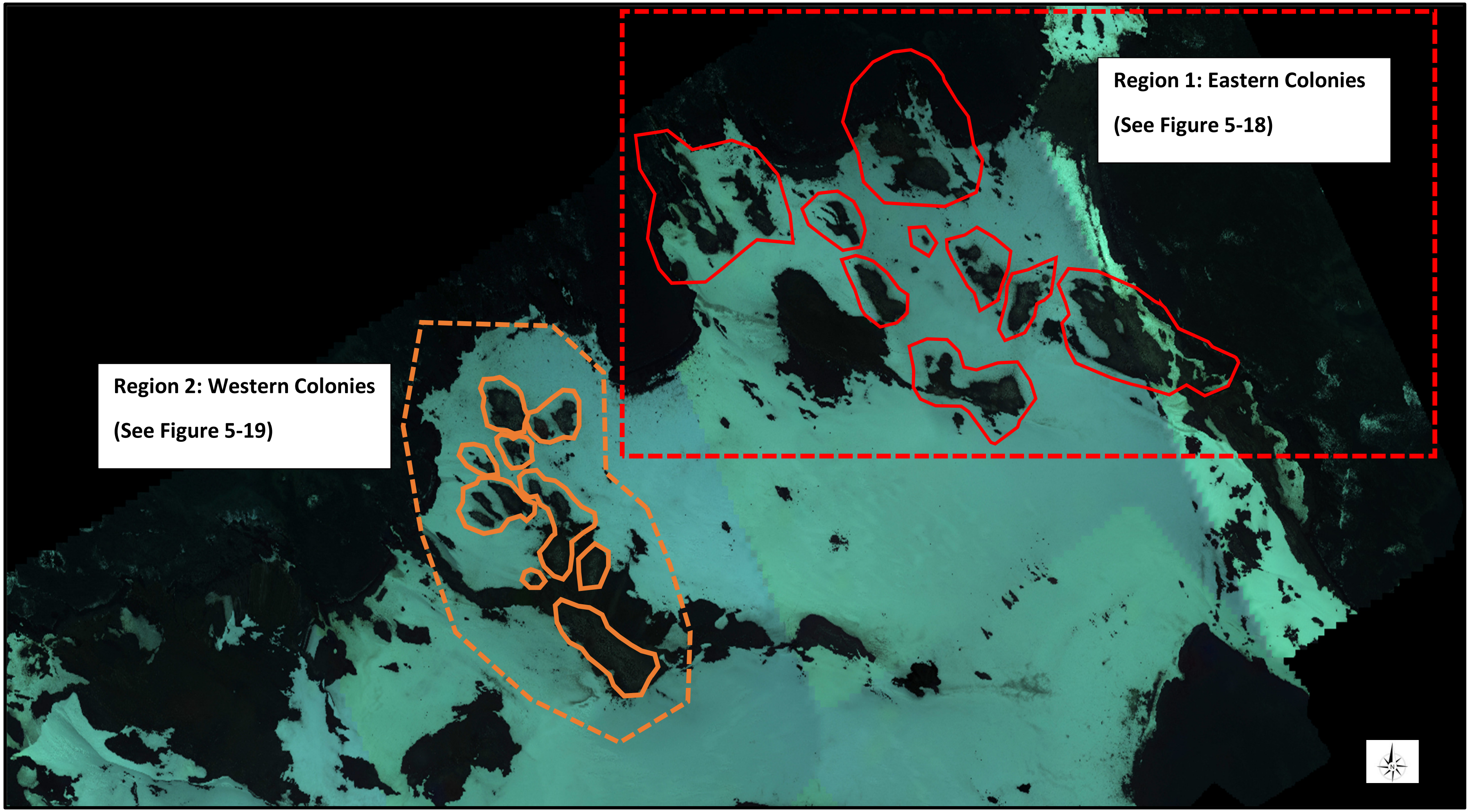


Figure 5-18 Region 1 (Eastern) *Pygoscelid* Colonies (with Respective Colony Numbers)

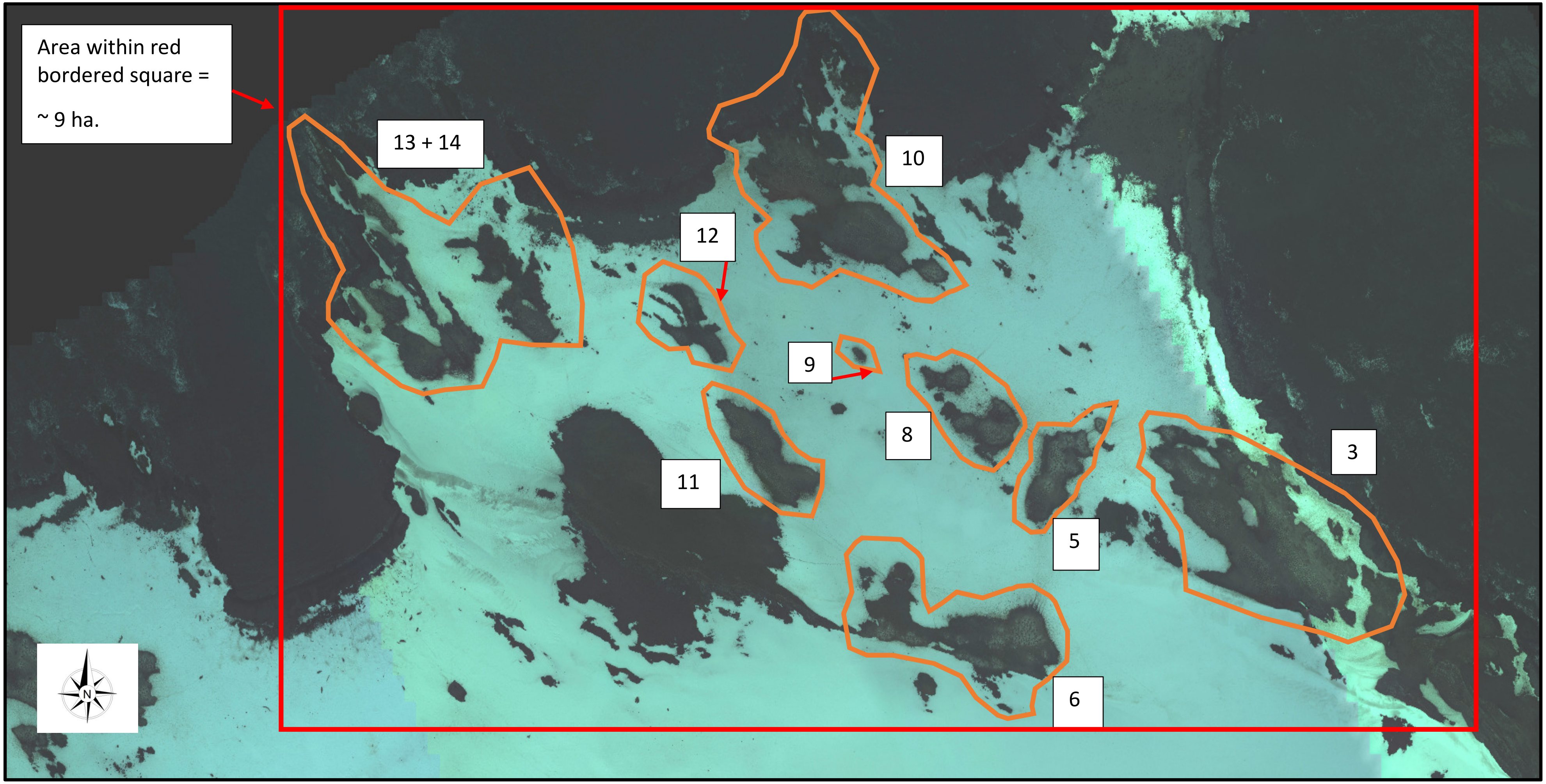
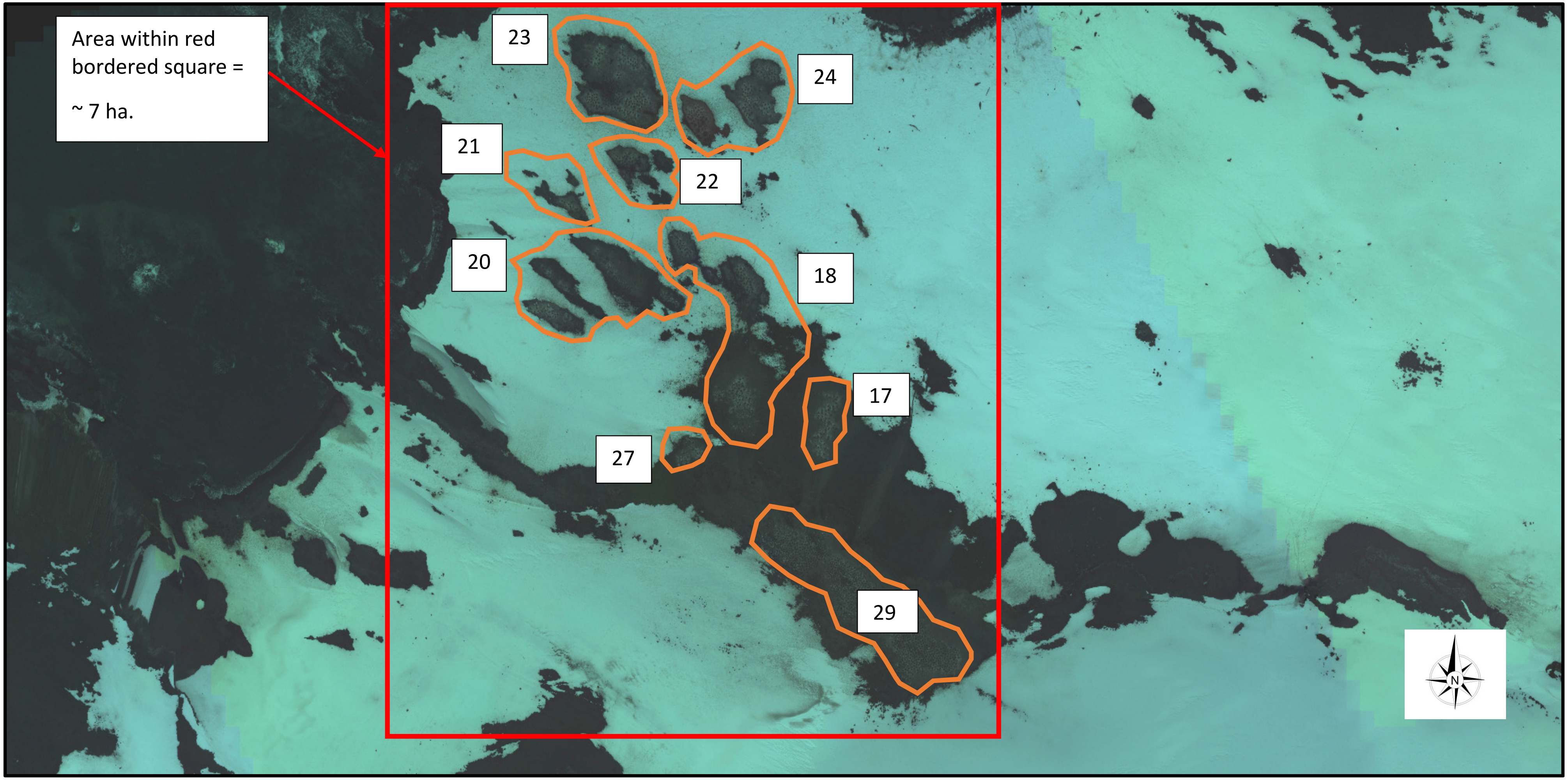


Figure 5-19 Region 2 (Western) *Pygoscelid* Colonies (with Respective Colony Numbers)



5.7 Objective 2 (Area-Density) – Research Investigations

The area-density investigations pertain to two explorations: firstly, to determine whether accurate nest-to-nest distances can be established for the two species utilising the results from the population census studies (section 5.4 & chapter 6); and, secondly, to establish whether accurate density figures can be established based on census and area information, together with the knowledge accrued from earlier stages (chapter 7).

Note: the *nest-to-nest distances* as described here are defined as the distance from the central mass of one nest to the central mass of its *nearest neighbouring* nest; whilst *nest densities* are determined as the number of nests per square metre (m^2).

5.7.1 Investigation 1: Calculating Nest-to-Nest Distances

One of the key outputs from the semi-automated approach detailed earlier – and thus from ImageJ - is the provision of pixel coordinates which are integral to the determination of the area-density calculations described in chapters 7 and 8. ImageJ does not, however, have geo-referencing capabilities, i.e. the 'x' and 'y' coordinates which are specific to each identified object only relate to the ImageJ image itself, rather than to a 'real world' physical location. Georeferencing is critical to remote sensing imagery as it enables objects such as penguin nests to be represented within an image in the actual location that such an object would be found in the environment, within accepted degrees of accuracy dependent on the precision of the geographical positioning system, the projection used, and the resolution of the imagery.

Providing the parent imagery has some form of georeferencing, it is possible to calculate the geo-referenced coordinates of a pixel from the 'x' and 'y' coordinates providing an identical copy of the parent image has been used to gain these 'x' and 'y' coordinates[36]. The process and equation for doing so are as detailed within appendix 11.

Once all the coordinates had been acquired for the identified nests for all colonies comprising the Cape Shirreff rookery, the geo-references were used to establish the distances between each nest (chapter 7) via the use of a computer programme that was developed within GNU Octave and which computerised the distances between identified objects in terms of 'nearest neighbours'. This programme was developed by Dr. Gareth Rees of SPRI following discussion between the two of us with regards to its parameters, whilst I interpreted and

[36] *Pers. Comm.* with Dr. Gareth Rees of SPRI on the 17^{th} of April 2015.

modified the output data for use within QGIS. The programme, with explanatory notes, is as shown in appendix 11.

Spatial Representation of Colonial Nest-to-Nest Distance within QGIS

Once all geo-referenced information had been acquired and had been modified for use within QGIS, the data was critiqued in terms of such variables as the minimum and maximum nest distances within a colony, average nesting distances and, significantly, to determine the average nest density per square metre (chapter 7).

To be able to best illustrate the range of nest-to-nest distances for each colony, I examined the outputs for all colonies to determine the minimum and maximum distances for each nest and to establish distance 'classes' for spatial representation. Allowing for a considerable degree of error, I cautiously set the minimum distance to 40cm and the maximum distance to 195cm, based on a critique of the data for all 4,007 nests previously identified, and conscious that from this analysis, any distance of under c. 50cm, or over c. 1.8m, were extremely unlikely to be identifying nest-to-nest distances but rather nest-to-rock distances, lone, non-breeding individuals, shadows, or some other object causing confusion or interference.

The decision was also based on the very limited available literature on the topic, specifically, from Davis & Renner (2003) who describe gentoo penguins typically building large nests and with colonies being less densely populated; and, the seminal work of Stonehouse (1975) who states that the:

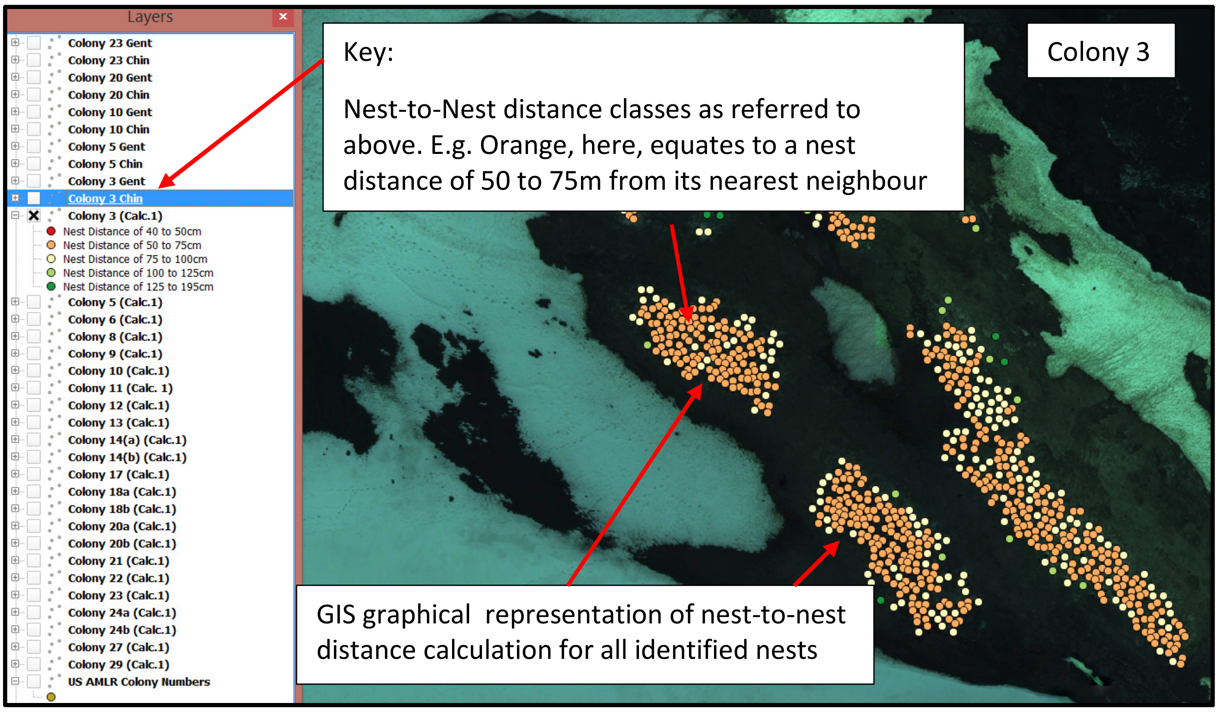
- the nests of the gentoo penguin at South Georgia, ranged between 92.1cm and 119.2cm in size, and averaged 103.4cm;
- whilst the minimum distance between the nests of chinstrap penguins was an average of 86.3cm.

Given the above, I felt it important to design *asymmetric* classes between the range of 40cm to 195cm, to allow for a greater definition of distances between the presumed preferred nest-to-nest densities of the two species. Thus, the first and last classes may be assumed to comprise non-nest objects (but that this assumption would require in-situ confirmation for categorical conclusions to be made). The following distance classes were uniformly adopted for all colonies:

- Class 1: 40 to 50cm (represented as a solid red dot within QGIS; see below & figure 7-3);
- Class 2: 50cm to 75cm (orange);
- Class 3: 75cm to 100cm (yellow);

- Class 4: 100cm to 125cm (light green); and,
- Class 5: 125cm to 195cm (dark green).

Which are represented within QGIS as shown in the screen-print example below:



5.7.2 Investigation 2: Nest Densities

As this heralds the culmination of the research, the discussion with regards to nest densities is reserved for chapters 7 and 8.

5.8 A Note on Subsequent Chapters

Whilst the preceding chapters have provided the context and background to the research, the remaining chapters allow for a detailed exposition of the research methodologies and findings, namely: chapter 6.0 presents the results and the discussion of such results from the objective 1 investigations (i.e. the use of the open-source software discussed earlier to count and locate penguin nests whilst testing the three counting approaches described here); chapter 7.0 presents the results and the discussion of results from the objective 2 investigations; and, chapter 8.0 details the conclusions and recommendations for future research.

6.0 Objective 1 (Population Census): Results & Analysis

This chapter presents the results generated from the testing of the three research methodologies in terms of addressing the requirements of the first research objective (section 6.1); with full analysis and discussion following (6.2).

6.1 Research Methodologies: Results

The results are detailed within a series of figures and tables, comprising: a comparison of the results from the three approaches to the US AMLR data for the 2013-14 season (tables 6-1 to 6-3); a comparison of the population census results from all the approaches for region 1 and 2 colonies (figures 6-1 and 6-2, respectively), including an assessment of relative accuracies achieved with such results; and graphical representation of the time records for each approach for colonies of less than 250 nests (figure 6-3) and of 250 or more nests (figure 6-4). All investigations followed the methodologies described within the preceding chapter.

Table 6-1 Manual Counting Results & Comparison to US AMLR Data for Cape Shirreff Colonies [a]

Colony Number	Time Taken (in Seconds)	Total Number of Nests (Breeding Pairs)	US AMLR Ground-Count Data			Count Differences Over-Counting Under-Counting
			Chinstrap	***Gentoo***	**Total**	
Region 1: Eastern						
3	718	705	*709*	*31*	740	-4.73%
5	244	156	*81*	*82*	163	-4.29%
6	152	116	*0*	*130*	130	-10.77%
8	140	114	*74*	*94*	168	-32.14%
9	47	16	*30*	*0*	30	-46.67%
10	472	474	*464*	*18*	482	-1.66%
11	357	402	*399*	*0*	399	+0.75%
12	58	53	*53*	*0*	53	0.00%
13	418	334	*107*	*0*	107	-10.70%
14			*267*	*0*	267	-4.73%
Region 1 Totals	2,606	**2,370**	*2,184*	*355*	**2,539**	**Regional Accuracy [b] = 93.34%**
Region 2: Western						
17	82	60	*0*	*56*	56	+7.14%
18	159	102	*0*	*135*	135	-24.44%
20	213	113	*91*	*34*	125	-9.60%
21 [c]	25	7	*0*	*7*	7	0.00%
22	51	32	*0*	*33*	33	-3.03%
23	239	199	*65*	*120*	185	+7.57%
24	163	126	*0*	*99*	99	+27.27%
27	44	15	*13*	*0*	13	+15.385
29	1,008	983	*938*	*0*	938	+4.80%
Region 2 Totals	1,984	**1,637**	*1,107*	*484*	**1,591**	**Regional Accuracy [b] = 97.19%**
Cape Sherriff Rookery Totals:						
	4,590	**4,007**	***3,291***	***839***	**4,130**	**Manual Count Accuracy [b] for Whole Rookery = 97.02%**

Notes:

[a] Each colony was counted and recounted until two consecutive counts gave the same result. Each count was timed in seconds, with the figures above reflecting the average time taken for the two consecutive counts. Each count represents the total nests identified for both *P. antarctica* (chinstrap) and *P. papua* (gentoo) penguins, combined, rather than an attempt to differentiate between the two species which was not deemed possible (at the stage of assessment) for all colonies due to image clarity issues.

[b] Accuracy, here, is defined in terms of a comparison of the number of nests identified via the manual counting approach with the number of nests identified by the US AMLR for the 2013-14 season.

[c] US AMLR Colony #21 was a failed colony in terms of breeding *Pygoscelids* for the 2013-2014 season.

Table 6-2 Compilation of Results from the US AMLR Ground-Surveys, Manual Counting, & Semi-Automated Counting of *Pygoscelid* Colonies at Cape Shirreff

COLONY DESCRIPTOR	US AMLR 2013-14 RESULTS	MANUAL COUNTING RESULTS	SEMI-AUTOMATED COUNTING RESULTS
Region 1 (Eastern)			
3	740	705	705
5	163	156	156
6	130	116	116
8	168	114	115
9	30	16	16
10	482	474	478
11	399	402	402
12	53	53	53
13	107	334	333
14	267		
Region 1 Totals	**2,539**	**2,370**	**2,374**
Region 2 (Western)			
17	56	60	60
18	135	102	102
20	125	113	109
21	7	7	7
22	33	32	33
23	185	199	199
24	99	126	126
27	13	15	15
29	938	983	970
Region 2 Totals	**1,591**	**1,637**	**1,621**
Cape Sheriff Rookery Totals	**4,130 nests**	**4,007 nests**	**3,995 nests**
Total Accuracy as a % of the US AMLR Ground Counts for the Rookery		**97.02%**	**96.73%**

Table 6-3 Compilation of Census Counting (Objective 1) Results from: US AMLR Data (2013-14), Manual Counting, Semi-Automated & Quasi-Automated Image Processing Approaches

		Approach 1		Approach 2		Approach 3	
Colony Number	**US AMLR Records (2013-14 Season)**	**Manual Counting**		**Semi-Automated**		**Quasi-Automated Counting**	
		Results (Nests)	**Accuracy (As % of US AMLR)**	**Results (Nests)**	**Accuracy (As % of US AMLR)**	**Results (Nests)**	**Accuracy (As % of US AMLR)**
Region 1 (Eastern) Colonies							
3	740	705	95.27%	705	95.27%	792	93.43%
5	163	156	95.71%	156	95.71%	178	91.57%
6	130	116	89.23%	116	89.23%	163	79.75%
8	168	114	67.86%	115	68.45%	172	97.67%
9	30	16	53.33%	16	53.33%	21	70.00%
10	482	474	98.34%	478	99.17%	489	98.57%
11	399	402	99.25%	402	99.25%	413	96.61%
12	53	53	100.00%	53	100.00%	62	85.48%
13	107	334	89.30%	333	89.04%	402	93.03%
14	267						
Region Totals	2,539 Nests	2,370	93.3%	2,374	93.5%	2,692	94.3%
Region 2 (Western) Colonies							
17	56	60	93.33%	60	93.33%	51	91.07%
18	135	102	75.56%	102	75.56%	102	75.56%
20	125	113	90.40%	109	87.20%	109	87.20%
21	7	7	100.00%	7	100.00%	7	100.00%
22	33	32	96.97%	33	100.00%	33	100.00%
23	185	199	92.96%	199	92.96%	199	92.96%
24	99	126	78.57%	126	78.57%	126	78.57%
27	13	15	86.67%	15	86.67%	15	86.67%
29	938	983	95.42%	970	96.70%	970	96.70%
Region Totals	1,591 Nests	1,637	97.2%	1,621	98.2%	1,612	98.7%
Rookery [a] Summary	**4,130 Nests**	**4,007**	**97.0%**	**3,995**	**96.7%**	**4,304**	**96.0%**

Note:

[a] Percentages as a proportion of the total number of all nests for the rookery in its entirety as compared to US AMLR data.

Figure 6-1 **Region 1**: Comparison of Colony Totals from: US AMLR Data (2013-14), Manual Counting, & Semi-Automated & Quasi-Automated Counting Approaches with Accuracy Comparisons

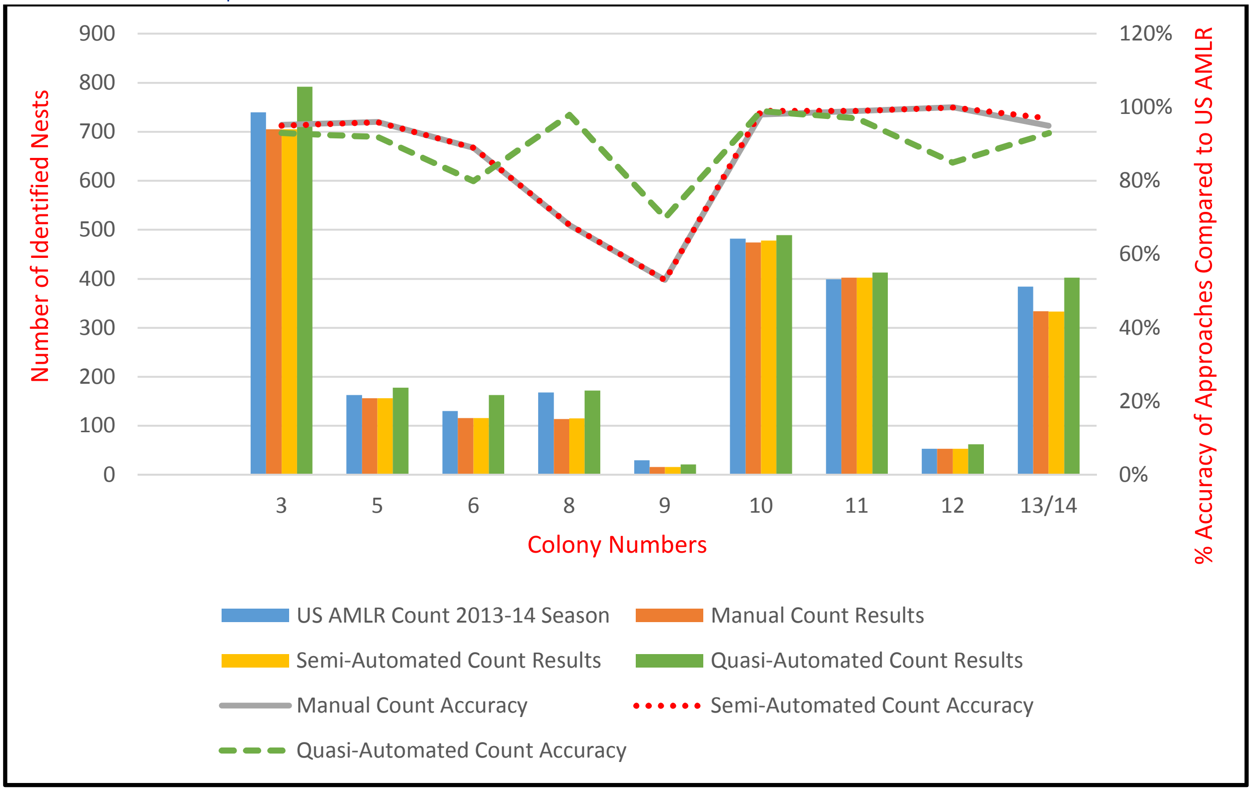


Figure 6-2 **Region 2**: Comparison of Colony Totals from: US AMLR Data (2013-14), Manual Counting, & Semi-Automated & Quasi-Automated Counting Approaches with Accuracy Comparisons

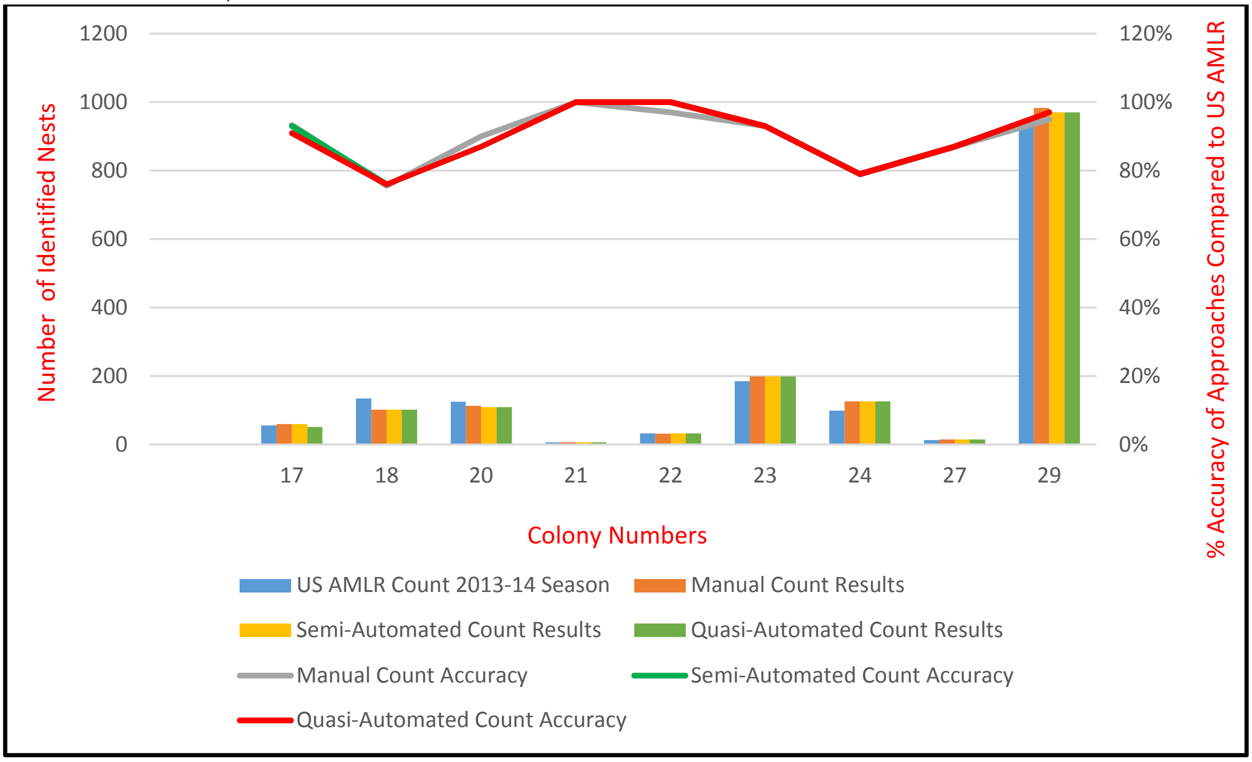


Figure 6-3 Graphical Representation of the Counting Time Records for all Colonies of Less Than 250 Nests

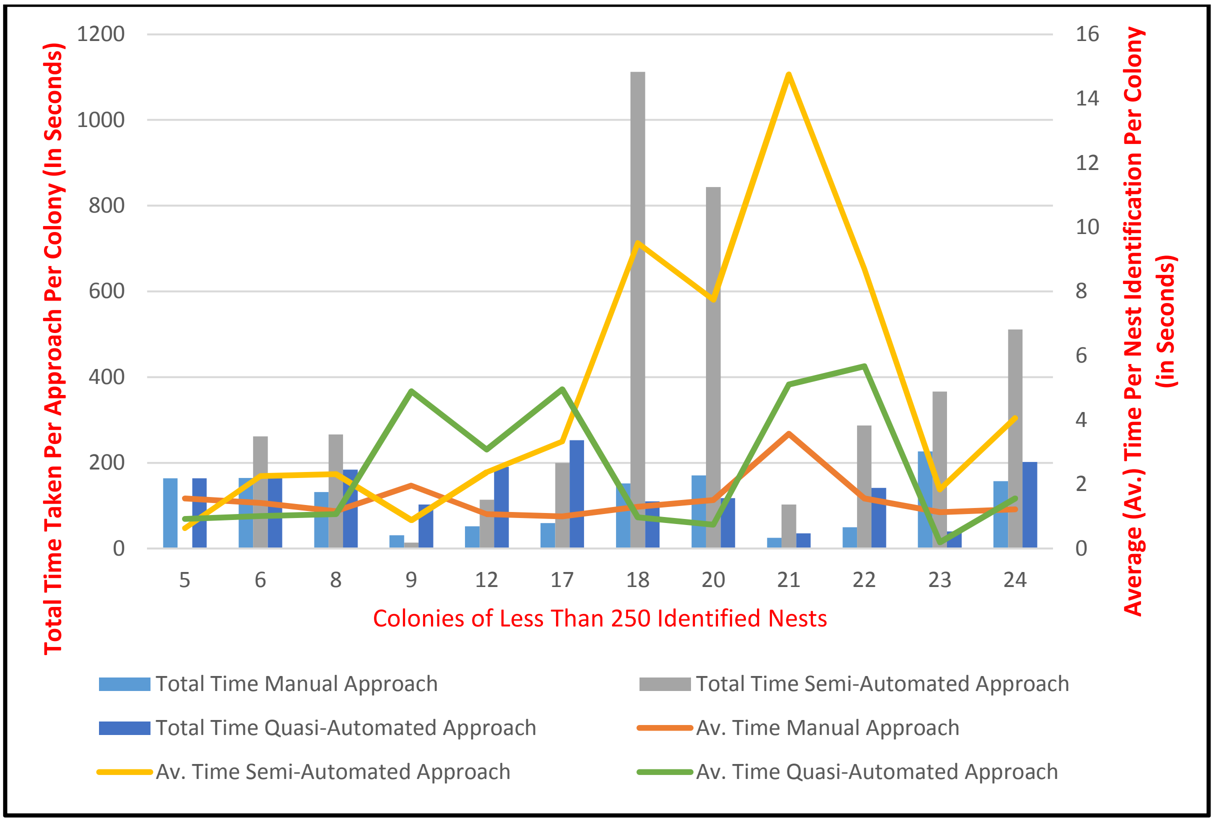
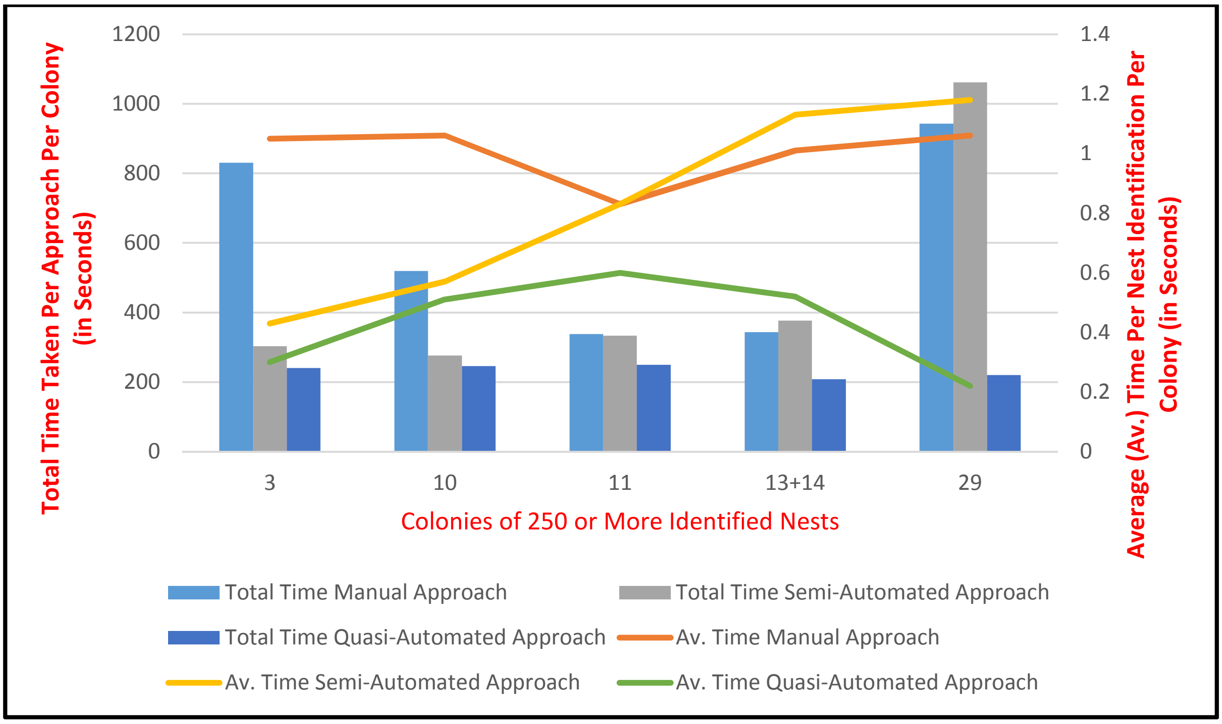


Figure 6-4 Graphical Representation of the Counting Time Records for all Colonies of 250 or More Nests



6.2 Analysis & Discussion of the Objective 1 Population Census Results

6.2.1 Cape Shirreff Rookery Population Census: Analysis of Result

The US AMLR *Pygoscelid* population data for the 2013-2014 monitoring season at Cape Shirreff[37] was received several days after completing the manual counting exercise. Appendix 7.0 provides for the full data received.

As intimated earlier, the first observation is that for the approaches described here, the clarity of the imagery is of the upmost importance. It is a truism that should the objects being observed not be sufficiently differentiated from their background, with or without image modification, then interpretations will require a degree of caution. The imagery for the western colonies was generally better than that for their eastern counterparts, particularly in relation to the coastal fringe colonies 3, 10, 13, and 14, where the coastal waters appear to cause a modicum of image disruption in terms of identifying nests at the micro level. Whilst not believed to have caused significant issues in terms of overall nest identification, this is a finding that should be considered when designing future research and all results should therefore be treated with moderate caution. The investigations to date and the experience acquired during the lengthy trialing and experimentation periods, would suggest that an error rate of c. +/- 10% may be reasonably expected.

The US AMLR identified 4,130 *Pygoscelid* nests across the nineteen colonies, in comparison to the 4,007 nests that were manually counted and which represented an accuracy of ~97% (table 6-1). The small error rate may be due to human error, such as through miscounting; omissions, such as due to image clarity issues; or, due to population changes over time - whilst the US AMLR ground-count and the BAS aerial imagery are from the same 2013-14 season, the potential, pronounced, inter-annual variations exhibited by the species at other colonies suggest that this may be a significant contributing factor.

The whole-rookery population results from the semi-automated approach also compare favourably with the US AMLR data, representing an accuracy of 96.7% or 3,995 nests identified (table 6-2); whilst the quasi-automated approach returned a count of 4,304, overestimating the number of nests by c.4% but still providing an accuracy of ~96% (6-3).

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[37] Source: Hinke, US AMLR, 2015, *Pers. Comm.*, via Dr. P. Trathan, BAS.

6.2.2 Cape Shirreff Colonies: Analysis of Regional Results

From table 6-3, and figures 6-1 and 6-2: the accuracy of the region 1 colony counts from the manual counting approach (2,370 of 2,539 nests or 93.3%) and semi-automated counting approach (2,374 nests/93.5%) were (comparatively) lower than those from the quasi-automated approach (2,692 nests/94.3%). With an error rate of not more than 6.7%, the results positively correlated with the US AMLR data but were still lower than those for the region 2 colonies, which ranged from an accuracy of 97.2% (1,637 nests as opposed to 1,591), to 98.2% (1,621 nests) and 98.7% (1,612 nests) for the semi-automated and quasi-automated approaches, respectively.

Of note is that the region 2 colonies only account for a little in excess of a third of the total number of nests counted by the US AMLR (1,591 nests from a total rookery count of 4,130, or ~39%). Whilst, intuitively, we may expect accuracies to be greater for smaller colonies, one colony (29) accounts for more than a half of all of the nests identified by the US AMLR within the region 2 colonies equating to 938 of the 1,591 nests identified, or 59% of all region 2 records which does, of course, significantly skew the results. Notwithstanding this, the *average* per-colony accuracies (as calculated from the individual accuracies of each colony count from the three approaches and the mean of the three resultant counts) for region 1 and 2 colonies is very similar, at 88.8% for region 1, whilst for region 2 it is marginally greater at 90%. Indeed, the results are the same when the regional averages of the manual nest counts are considered in separation (perhaps the most important of the three approaches in this regards), potentially indicating that colony size *per se* would not appear to have any great bearing on the accuracy of manual counting results. This is further evident when the accuracies of the manual count for the largest colony within each region are examined: for region 1, this is colony 3, where the manual approach accounted for 705 of the 740 nests, an accuracy of ~95%; compared to the equivalent region 2 colony (29), where an accuracy of 95% was also recorded (equating to an over-count of 983 nests *v.* 938 nests).

6.2.3 Colonies of Less Than 250 Nests versus Colonies of 250 or More Nests

When we compare the accuracy of counts for all colonies of less than 250 identified nests, with colonies of 250 or more identified nests [appendix 8, tables 8-a and 8-b, respectively], the following become apparent: the average of the accuracies for individual colony counts for the smaller colonies (<250 nests), range from ~86 to 87% for all three approaches; whilst for the colonies of 250 or more nests, all three approaches attain a striking accuracy of just over 95% (specifically, 95.5, 95.9, and 95.7% for the manual, semi-automated, and quasi-automated approaches, respectively), indicating, it is thought, that the larger the colony, the more appropriate the use of an automated approach would be.

6.2.4 Synoptic Assessment

The methodologies were also tested to determine whether using the quasi-automated approach could provide accurate results when used for a synoptic assessment of the entire rookery. Whilst the image required editing, and several attempts were required in terms of refining the threshold of the imagery, the end result was a seemingly very encouraging accuracy of 95%, identifying 4,347 nests by this means as compared to the total US AMLR count of 4,130. However, on closer inspection of the resulting output it became clear that the thresholding used had resulted in the misattributing of objects as nests and, despite other testing, the results did not improve. Confidence in this approach is therefore presently low. Within the examples shown in chapter 5 (figure 5-12), colony 11 (c. 400 nests) appeared almost entirely missed by the approach, with the results for the other colonies being similarly disappointing, aside from colonies 5 and 6, the nests from which appear relatively well represented. Checking the master imagery from BAS, all of the colonies used within this example are surrounded by snow/ice, other than for colony 29 which has ice on its eastern and southern fringes, only; whilst colonies 29 and 6 appear marginally different in terms of having less uniform relief but neither factor (ice or terrain) appears to be influencing the findings of this particular approach.

6.2.5 Analysis of Time Records

A detailed log of the time taken to produce the census records for each colony, or section thereof, was compiled so that a comparison could be made of the relative efficacies of each approach. The full records are noted within tables 8-a and 8-b within appendix 8, and table 9-a within appendix 9, but the most salient aspects are reflected here within figures 6-3 and 6-4. The colonies were divided into the same small (<250 nests), and larger (250 and more nests) categories used earlier. It should be noted that the timings are processing times, only, they do not, for example, include the time taken to load the imagery into the software programs.

From the analysis, the two most important observations are that, firstly, for *colonies of less than 250 nests*, the results from the manual and quasi-automated approaches were similar, whilst the semi-automated approach was clearly an inconsistent one, reflecting the background tasks that were required to set-up the software in the first instance. However, given that lessons were learnt during the semi-automated phase from which inferences could be made when adopting the quasi-automated phase, it seems unlikely that either approach would be suitable for small colonies in terms of time; secondly, for *colonies of 250 or more nests*, the average time taken to identify each nest was substantially lower for the quasi-automated approach (~0.45s) as compared to the manual (~1.02s) and semi-automated (~0.86s) approaches, with the manual approach, not surprisingly, proving the lengthiest approach for all but one colony.

When coupled with the average accuracy of the quasi-automated approach for these larger colonies (~95.1%), it would seem to stand to reason that this more autonomous approach would be more applicable to larger colonies and, indeed, would prove of significant benefit. Whilst, intuitively, this was previously thought likely to be the case, the experiments allow such intuition to be underlined by statistical reality. Indeed, it might be reasonable to suggest that for future applications or experiments, the manual and semi-automated approaches described herein are continued to be used for colonies of, say, less than 1,000 nests, whilst the quasi-automated approach may prove more worthwhile for those colonies of greater than 1,000 nests, at least in terms of time, but that further experimentation is required in order to fully test this thought, particularly in terms of identifying and calculating any trade-offs between accuracy and time.

6.2.6 Imagery Difficulties

As intimated earlier, the clarity of an image occasionally presented issues of identification. Whilst these did not in the main cause significant problems, certain themes became evident: firstly, issues caused by *topography*, particularly in terms of varying relief within a confined area, resulted in difficulties in identifying objects in some instances (with the higher topographic relief within the eastern quarter of colony 17 and south-east corner of colony 11 being particularly salient examples); secondly, issues of analysis of *smaller sites*: colony 9, for example, presented pixilation issues when attempting to magnify the image; thirdly, the presence of *coastal waters*: one unexpected revelation was that the coastal waters located on the fringes of some colonies resulted in quite significant levels of ‘interference’ or disturbance within an image and consequent misidentification of extraneous objects as nests. These issues were particularly prevalent for colonies 3, 10, and 13/14, but were not deemed insurmountable; and, lastly, issues presented in relation to pronounced changes in *terrain and substrate* type within an image: colony 12, for example, provided some interpretative challenges due to considerable rocky areas being interspersed with sporadically higher terrain which would seem to mask the nests in certain areas, either through a shadowing-effect or simply by being mistaken for rocks.

Chapter 8 provides for further discussion of the results described here and when considered in light of the research as a whole.

7.0 Objective 2 (Area-Density): Results & Analysis

This chapter presents the results generated during investigations relating to the second research objective (section 7.1); with full analysis and discussion (7.2). Appendices 9 and 12 contains further output examples and aligned information.

7.1 Objective 2: Results

This section presents all of the results delivered whilst undertaking the objective 2 investigations. These are detailed within a series of figures and tables, namely: the results from the calculation of minimum and maximum nest-to-nest distances for the Cape Shirreff rookery as a whole (table 7-1; figure 7-4), and more comprehensive results from an example colony (figures 7-3 and 7-5), together with those for all congeneric colonies (table 7-2 and figure 7-6), and the analysis of chinstrap and gentoo penguins, individually (figures 7-7 and 7-8, respectively). Figure 7-9 provides for the mean nest-to-nest distances for species and nest distribution configurations. Figures 7-1 and 7-2 also provide GIS outputs to allow spatial representation of the nest classification results for region 1 and 2 colonies, respectively; with this results section culminating in an examination of nest-to-nest distances, densities and colonial structures within the rookery (tables 7-3 to 7-5; figures 7-10 and 7-11); and in table 7-6 which represents a synthesis of the key outputs from the statistical analyses undertaken.

Table 7-1 Cape Shirreff Rookery Colonies: Potential Minimum and Maximum Nest-to-Nest Distances in Metres (from ImageJ Data)

Colony	Minimum Nest-to-Nest Distance (metres) [a]	Maximum Nest-to-Nest Distance (metres) [a]	Minimum (m) (Rounded Down)	Maximum (m) (Rounded Up)
3	0.508383	1.896969	0.50	1.90
5	0.445881	1.663860	0.44	1.67
6	0.508383	1.881174	0.50	1.89
8	0.512320	1.622329	0.51	1.63
9	0.449802	1.342063	0.44	1.35
10	0.508383	1.692000	0.50	1.70
11	0.508383	1.299956	0.50	1.30
12	0.512654	1.450867	0.51	1.46
13+14	0.508383	1.136778	0.50	1.14
13+14	0.499005	1.276809	0.49	1.28
13+14	0.513153	1.035836	0.51	1.04
17	0.569000	1.590962	0.56	1.60
18a	0.705000	1.395829	0.70	1.40
18b	0.630571	1.854565	0.63	1.86
20a	0.508383	1.299956	0.50	1.30
20b	0.598212	1.595233	0.59	1.60
21	0.822164	1.576428	0.82	1.58
22	0.581358	1.196425	0.58	1.20
23	0.508383	1.838415	0.50	1.84
24a	0.564000	1.498851	0.56	1.50
24b	0.581358	1.261142	0.58	1.27
27	0.719736	1.311735	0.71	1.32
29	0.4019903	1.642350279	0.40	1.65
		Averages	**0.55m**	**1.5m**
Equates to an Averaged Nest-to-Nest Distance of ~1.02m				

Notes:

[a] Does not include obvious anomaly results.

Figure 7-1 Nest Classification Results for Region 1 (Eastern) Colonies

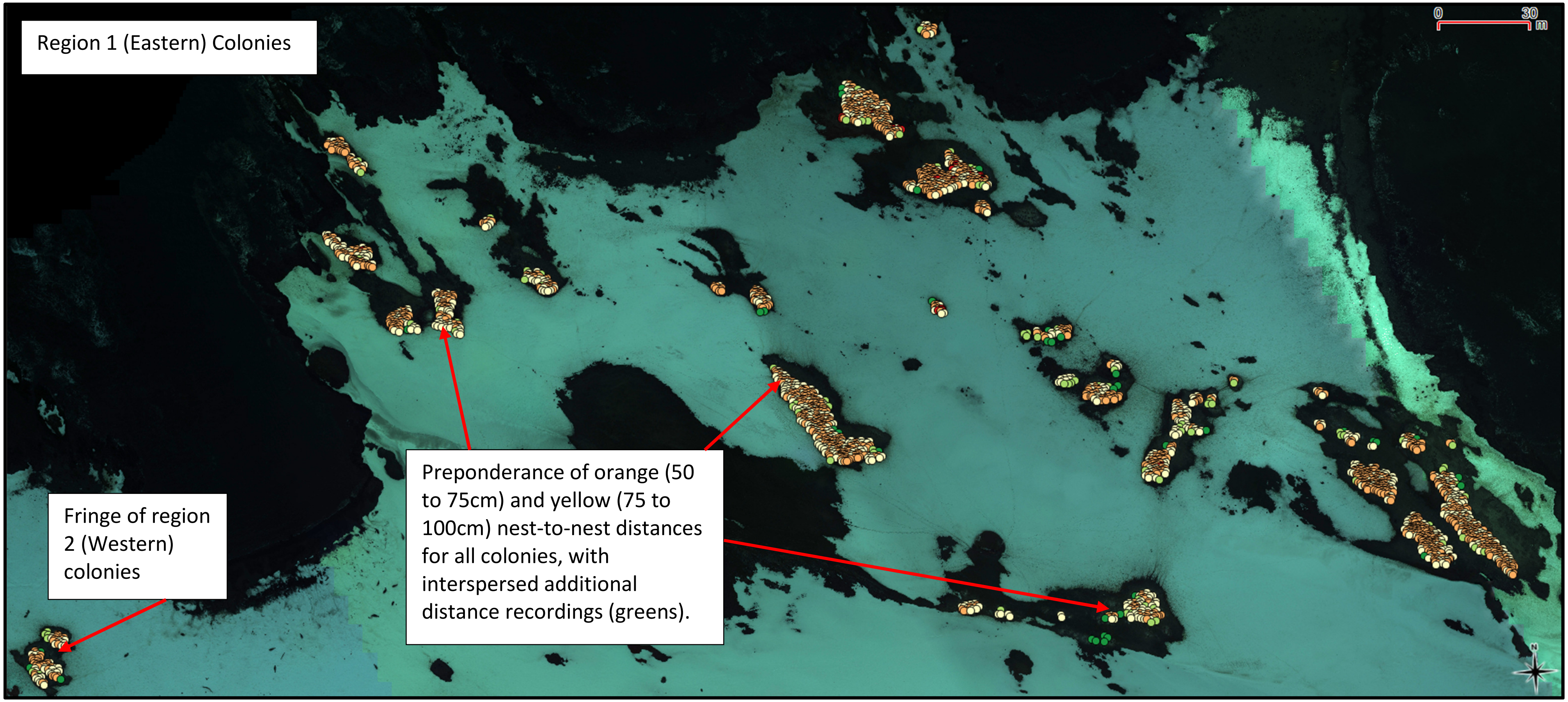


Figure 7-2 Nest Classification Results for Region 2 (Western) Colonies

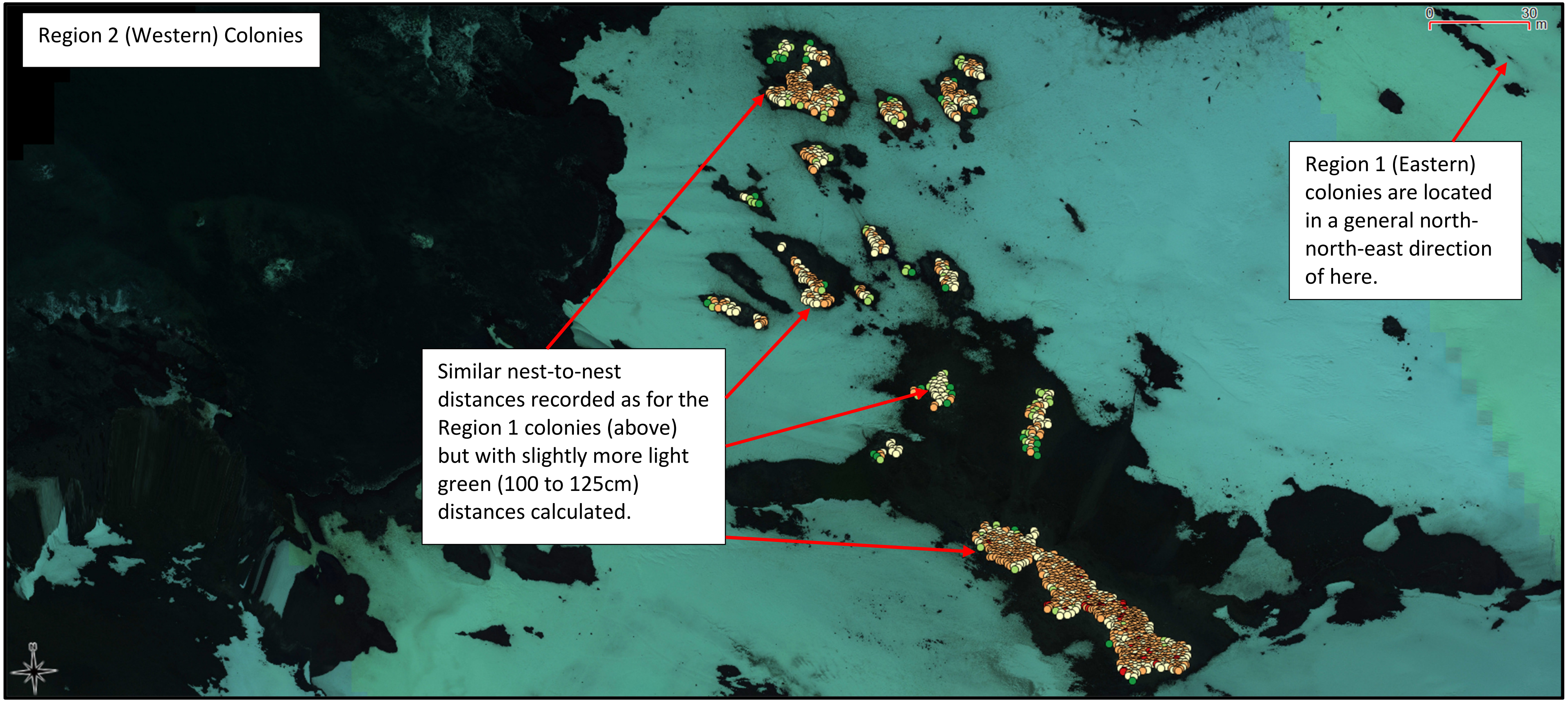


Figure 7-3 Example QGIS Output (Screen-Print): Post-Classification of Nest Distances (in Detail)

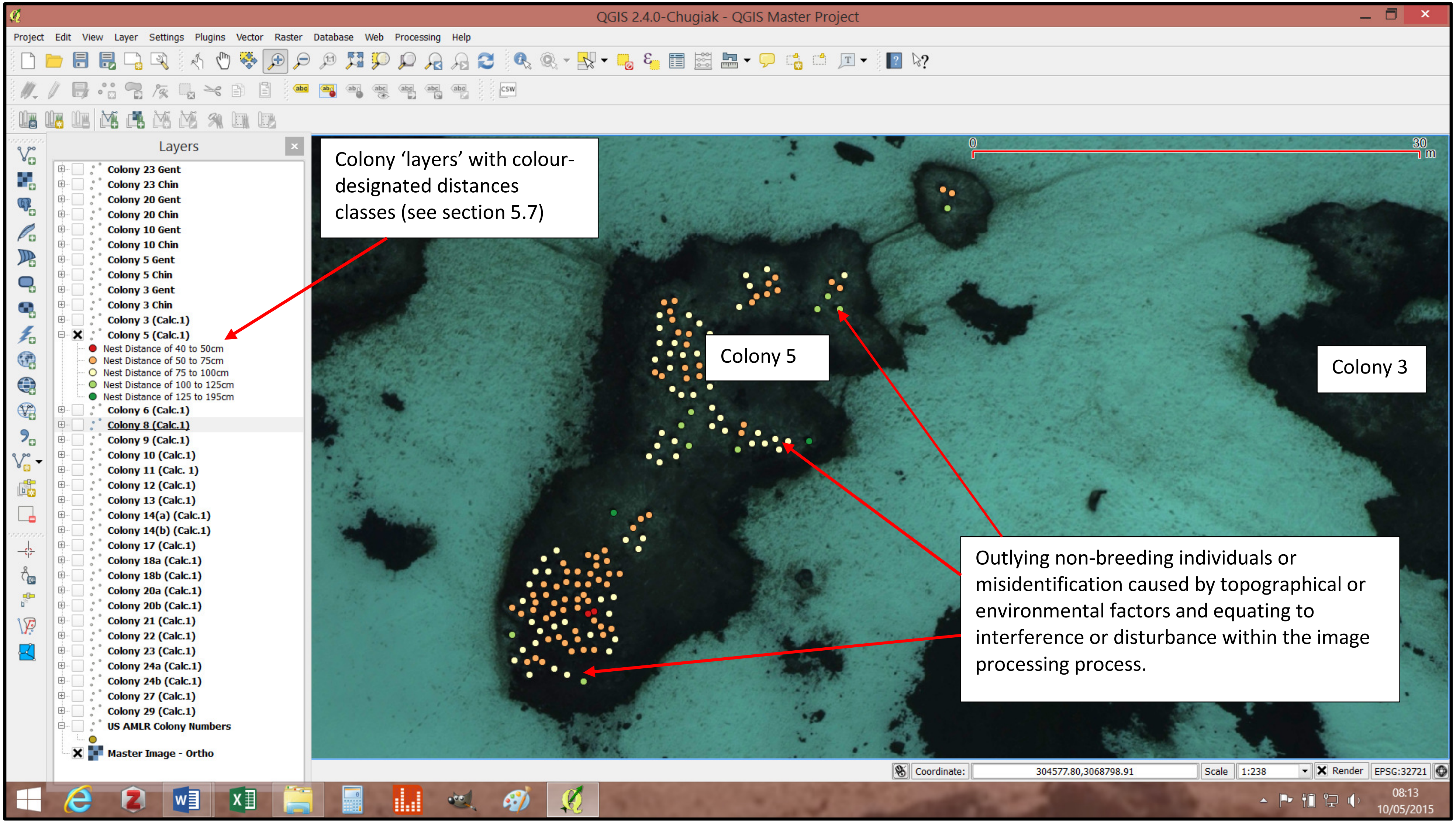


Figure 7-4 Nest-to-Nest Distance Results for *All* Colonies & *Pygoscelid* Species

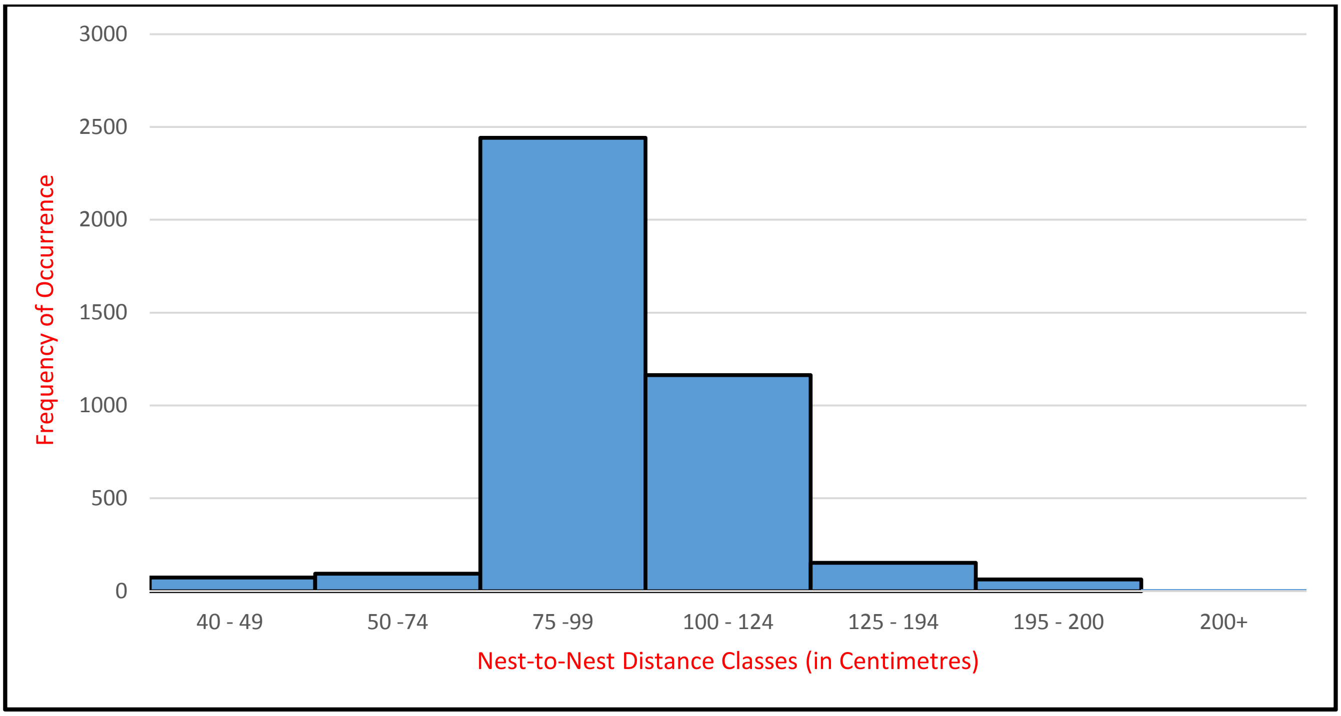
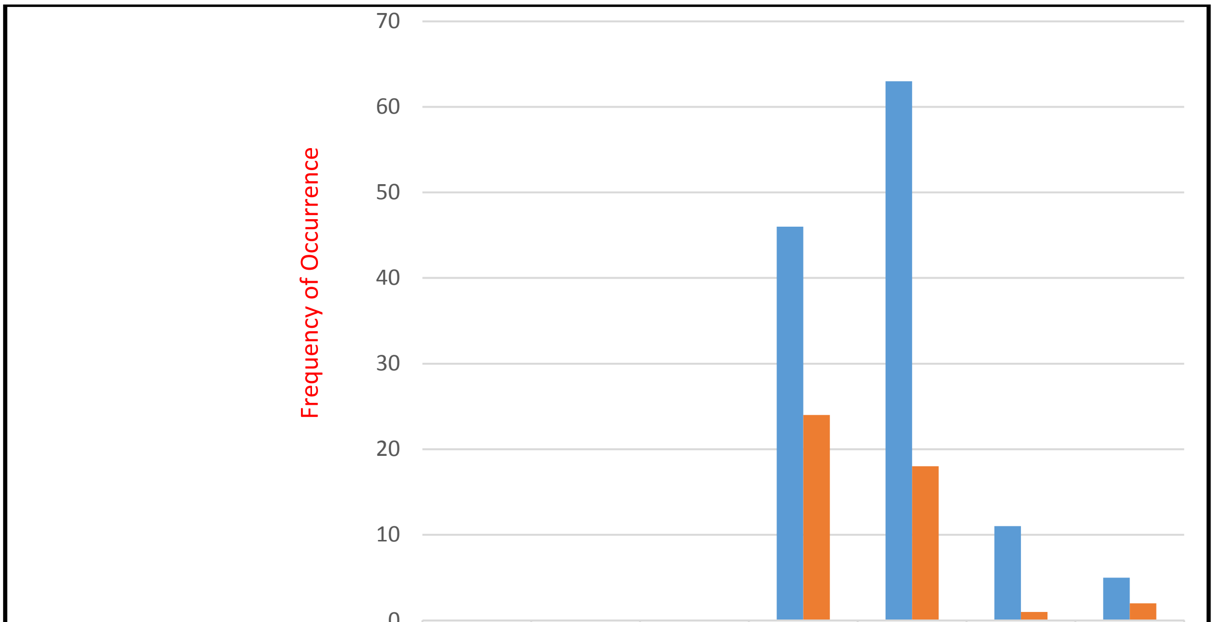


Figure 7-5 Nest-to-Nest Distance Example for a Congeneric Colony (23) with Data Table



	Below 40 cm	40 to 49 cm	50 to 74 cm	75 to 99 cm	100 to 124 cm	125 to 194 cm	195cm & Above
Chinstrap Nest-to-Nest Occurrences	0	0	0	46	63	11	5
Gentoo Nest-to-Nest Occurrences	0	0	0	24	18	1	2

Distance Classes & Number of Nest-to-Nest Distances Recorded

Chinstrap Nest-to-Nest Occurrences Gentoo Nest-to-Nest Occurrences

Table 7-2 Cape Shirreff Congeneric Colonies: Nest Counts & Minimum + Maximum Nest-to-Nest Distances

Colony	*P. antarctica* (Chinstrap) Nest Count [a]	*P. Papua* (Gentoo) Nest Count [a]	Chinstrap: Minimum – Maximum Nest-to-Nest Distance (m) [d]		Gentoo Minimum – Maximum Nest-to-Nest Distance (m) [d]	
			Minimum [b]	**Maximum [c]**	**Minimum [b]**	**Maximum [c]**
3	683	22	0.41	1.58	0.71	1.59
5	147	9	0.45	1.43	0.64	1.53
8	Species not identifiable from the imagery.					
10	456	18	0.43	1.31	0.59	1.43
20	64	49	0.59	1.14	0.59	1.29
23	74	125	0.51	1.34	0.51	1.31
			Average	*Average*	*Average*	*Average*
Totals	**1,424**	**223**	**0.48m**	**1.36m**	**0.61m**	**1.43m**
	Averaged Distances		**0.92m**		**1.02m**	

Notes:
[a] From the most accurate results attained from the three approaches detailed previously.

[b] Minimum figures are rounded down. [c] Maximum figures are rounded up.

[d] Does not include obvious anomalous results.

Figure 7-6 Nest-to-Nest Distances for all Identified Nests within the Cape Shirreff *Congeneric* Colonies

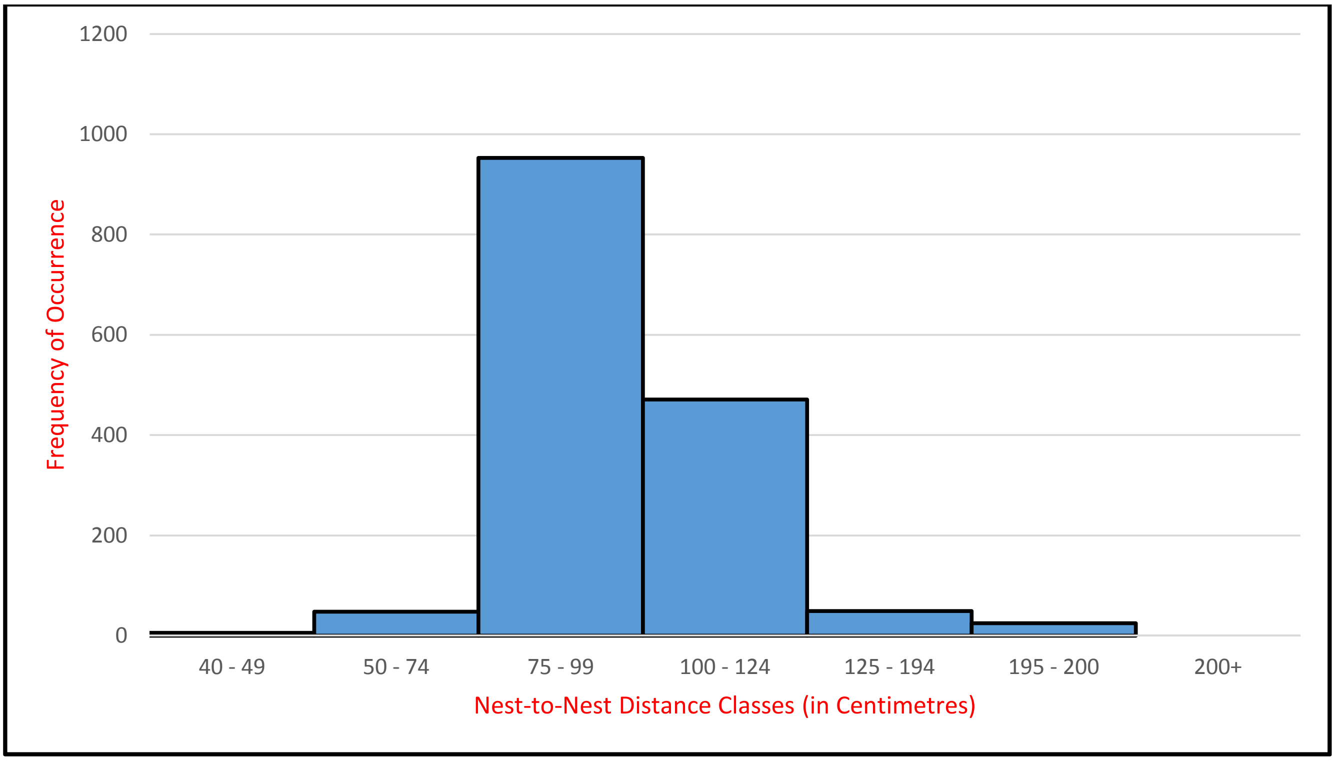


Figure 7-7 Nest-to-Nest Distances for all Identified *P. antarctica* (Chinstrap) Nests within the Cape Shirreff Congeneric Colonies

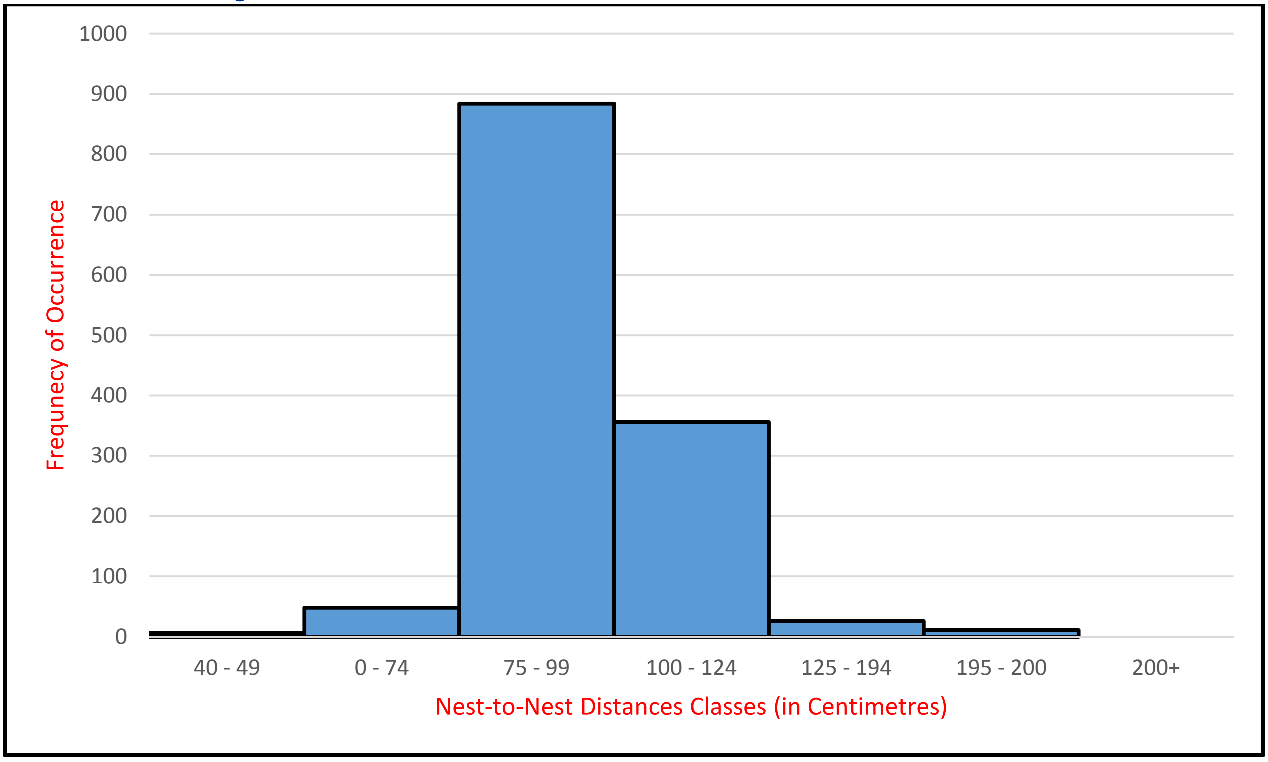


Figure 7-8 Nest-to-Nest Distances for all Identified *P. papua* (Gentoo) Nests within the Cape Shirreff Congeneric Colonies

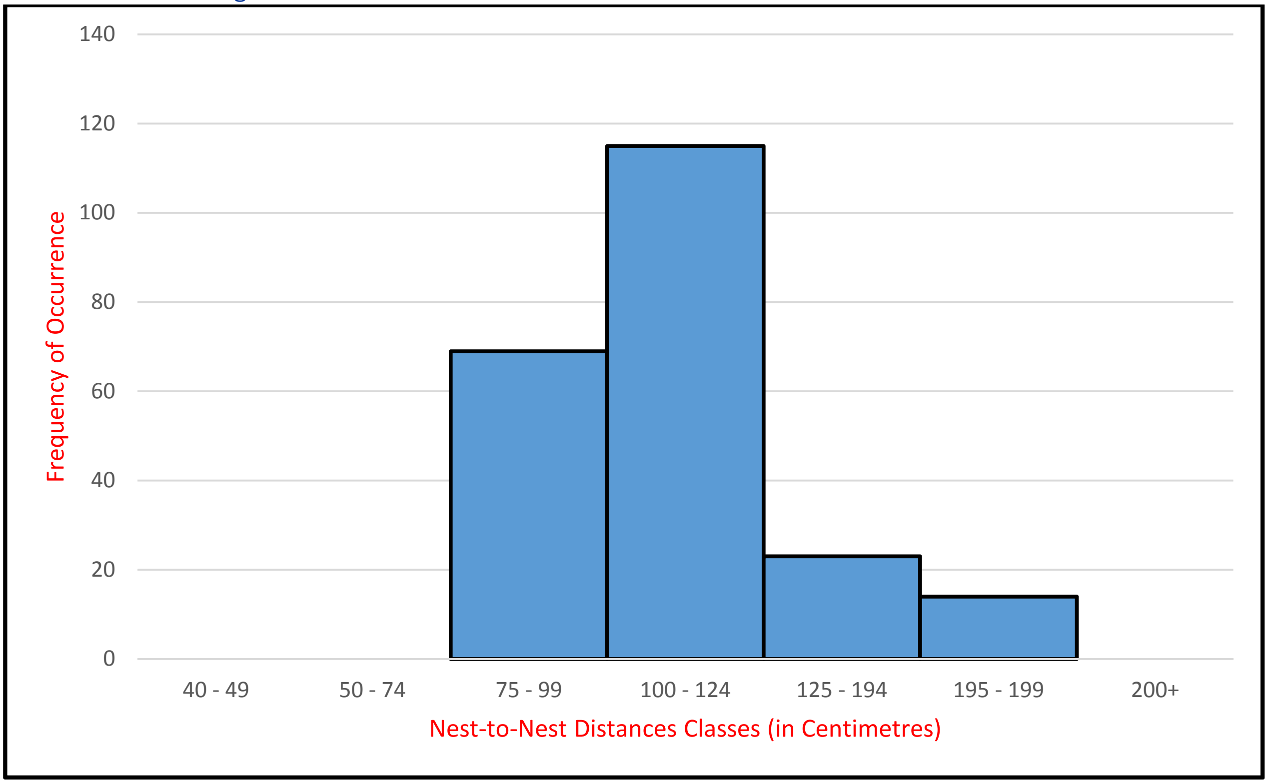


Figure 7-9 Mean Nest-to-Nest Distances between *P. antarctica* (Chinstrap) & *P. papua* (Gentoo) Nests at all Cape Shirreff Congeneric Colonies – with Mean Distance Data Labels (in Metres)

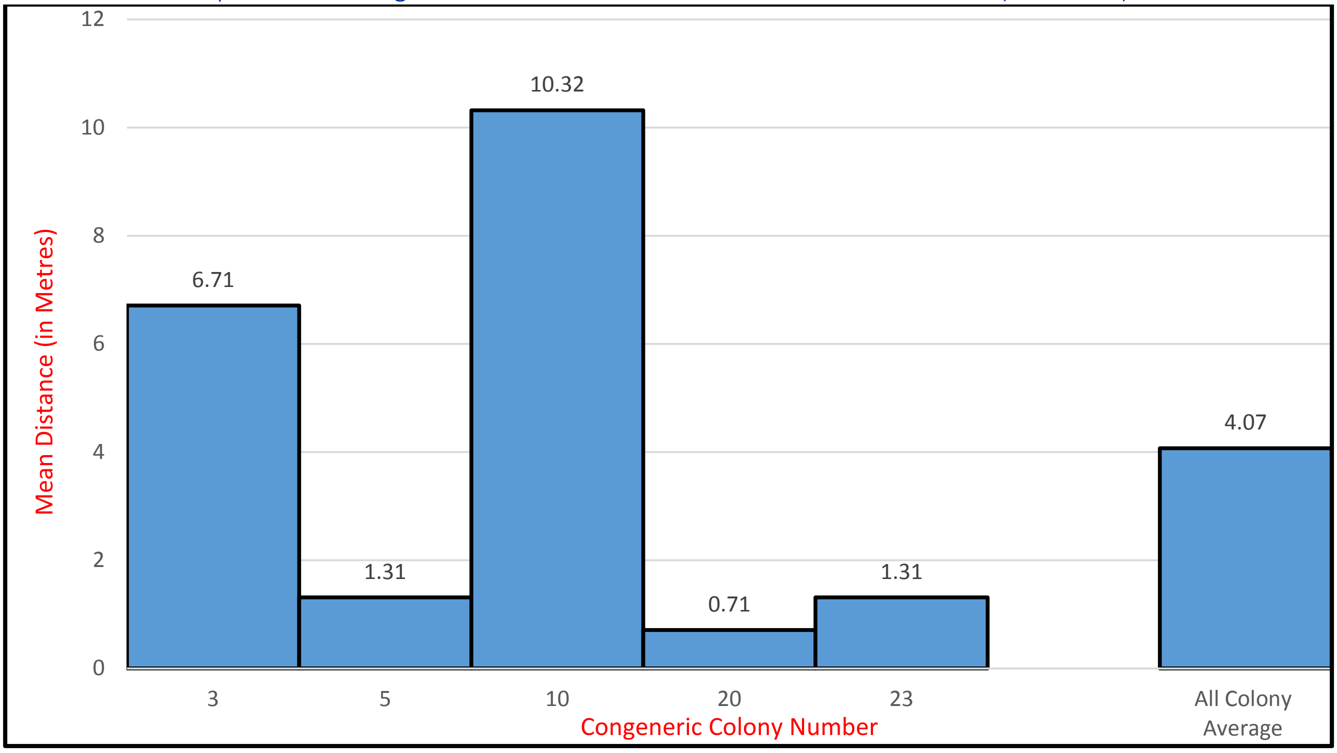


Table 7-3 Cape Shirreff Rookery Colonies: Approximate Nest Densities

Colony	Nest Count [a]	Approximate Initial Colony Area (m^2)	Revised Approximate Colony Area (m^2)	Density = Average Number of Nests per m^2 per Colony
3	705	2,991	789	1.12
5	156	562	324	2.08
6	116	1,487	475	4.75
8	172	613	267	1.55
9	21	17	10	0.48
10	478	2,176	854	1.79
11	402	692	409	1.02
12	53	368	120	2.26
13 + 14	333	1848	422	1.27
17	60	134	134	2.23
18	102	1,079	423	3.94
20	113	749	284	2.51
21	7	116.6	25	3.6
22	33	251	81	2.45
23	199	664	432	2.17
24	126	448	226	1.79
27	15	62	62	4.13
29	970	966	944	0.97
Totals	**4,061**	**15,224**	**6,281**	
Whole Rookery Density (Average Number of Nests per m^2 for All Colonies) = 2.23 Nests per m^2				
Note: [a] From the most accurate results attained from the approaches and results detailed in chapters 5 & 6.				

Table 7-4 Mean Nest-to-Nest Distances with Standard Deviations at Various Colonial Levels

Variable	Mean Nest-to-Nest Distance (cm)	Standard Deviation (cm)
All Congeneric Nests	76	22
All Chinstrap Nests	70	19
All Gentoo Nests	91	29
Region 1: Congeneric Nests	75	23
Region 1: Chinstrap Nests	66	20
Region 1: Gentoo Nests	96	64
Region 2: Congeneric Nests	78	20
Region 2: Chinstrap Nests	79	16
Region 2: Gentoo Nests	90	22

Table 7-5 *P. antarctica* & *P. papua* Colonies: Approximate Nest Densities

Colony	Nest Count [a]	Approximate Initial Colony Area (m^2)	Revised Approximate Colony Area (m^2)	Density (Average Number of Nests per m^2 per Colony)
P. antarctica **(chinstrap penguin)**				
9	21	17	10	0.48
11	402	692	409	1.02
12	53	368	120	2.26
13 + 14	333	1848	422	1.27
27	15	62	62	4.13
29	970	966	944	0.97
			Average Nest Density for all Chinstrap Colonies	**1.69 nests per m^2**
P. papua **(gentoo penguin)**				
6	116	1,487	475	4.75
17	60	134	134	2.23
18	102	1,079	423	3.94
21	7	116.6	25	3.6
22	33	251	81	2.45
24	126	448	226	1.79
			Average Nest Density for all Gentoo Colonies	**3.13 nests per m^2**

Figure 7-10 Region 1 (Eastern) Congeneric Colonies with *P. antarctica* & *P. papua* Nest Locations Differentiated

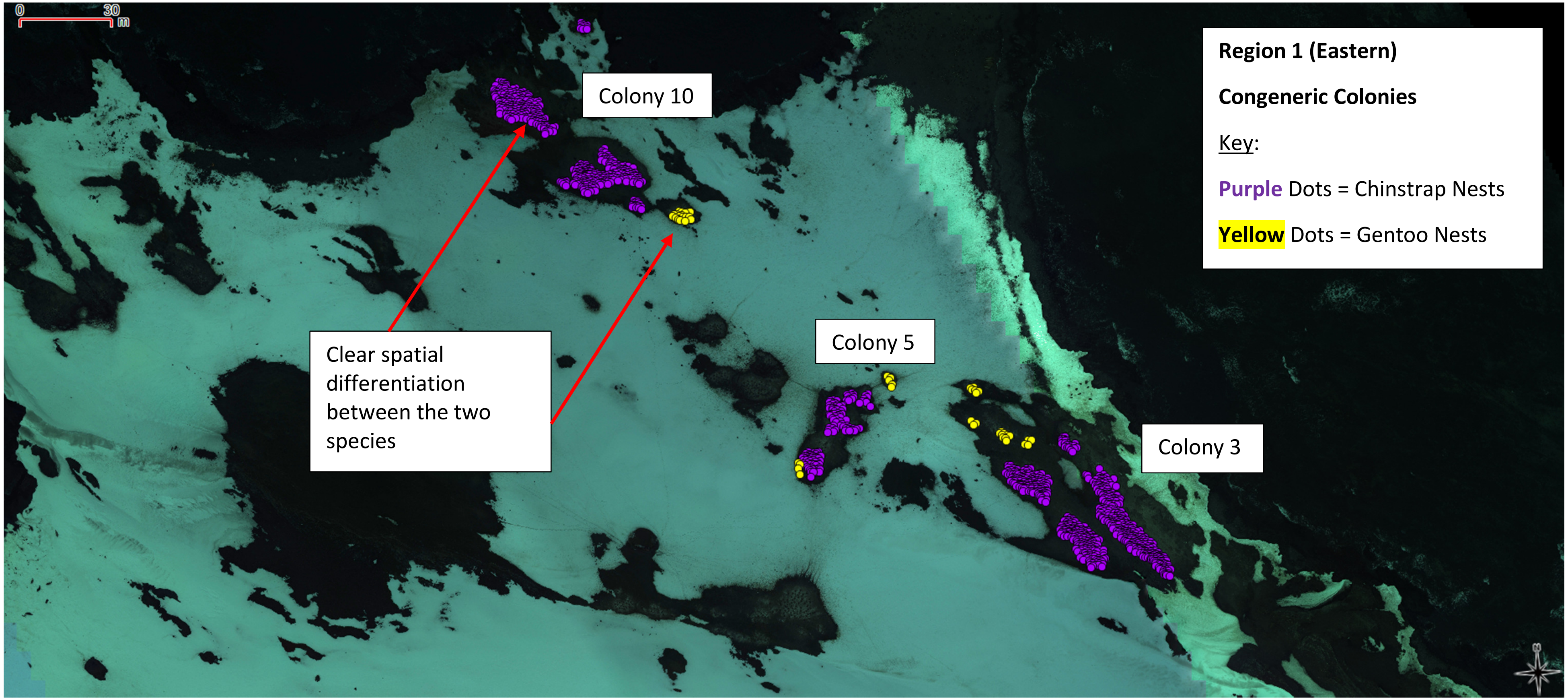


Figure 7-11 Region 2 (Western) Congeneric Colonies with *P. antarctica* & *P. papua* Nest Locations Differentiated

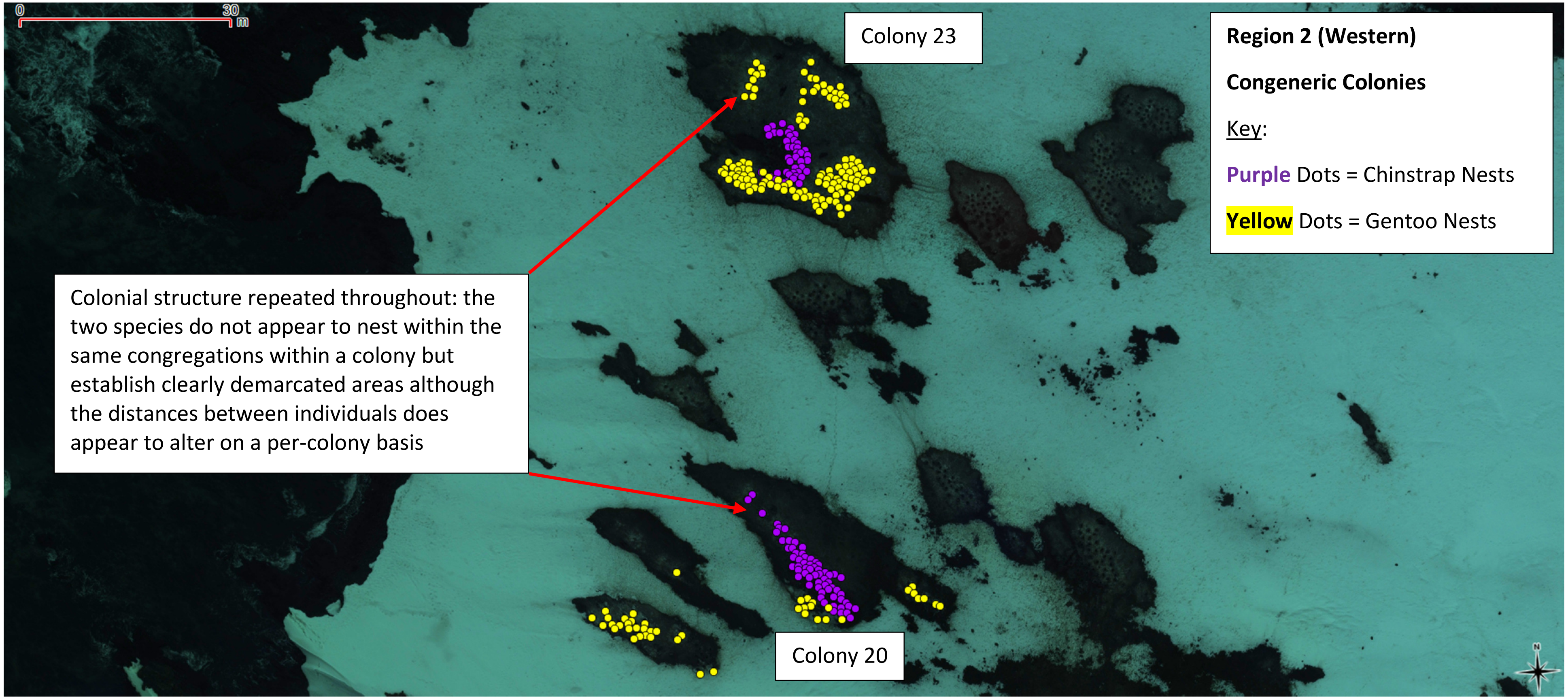


Table 7-6 Nest-to-Nest Statistical Analysis: Mean, Standard Deviation, t-Value, & p-Value

Variable	Number of Nests Identified	Mean Nest-to-Nest Distance (cm)	Standard Deviation σ (cm)	Welch's t-Test Value	Number of Degrees of Freedom	p-Value
Statistical Analysis #1: All Chinstrap v. Gentoo Nest Comparisons [a]						
All Chinstrap Nests	3,129	70	17	9.7718	700.237	1.6E-21
All Gentoo Nests	676	92	58			
Statistical Analysis #2: Non-Congeneric Chinstrap v. Gentoo Nest Comparisons [b]						
Chinstrap-only Colony Nests	1,794	70	19	14.5074	540.617	8.2E-41
Gentoo-only Colony Nests	444	91	29			
Statistical Analysis #3: Region 1 Chinstrap v. Gentoo Nest Comparisons [b]						
Region 1 Chinstrap-only Colony Nests	809	66	20	5.01361	118.24	9.5E-07
Region 1 Gentoo-only Colony Nests	116	96	64			
Statistical Analysis #4: Region 2 Chinstrap v. Gentoo Nest Comparisons [b]						
Region 2 Chinstrap-only Colony Nests	989	79	16	8.35239	447.23	4.2E-16
Region 2 Gentoo-only Colony Nests	328	90	22			
Statistical Analysis #5: Comparison of Region 1 and Region 2 Congeneric Colony Nests						
Region 1 Congeneric Nests	1,287	75	23	2.21187	454.484	0.01374
Region 2 Congeneric Nests	280	78	20			
Statistical Analysis #6: Region 1 v. Region 2 Chinstrap Nest Comparisons [b]						
Region 1 Chinstrap Nests	809	66	20	14.9783	1532.06	9.8E-48
Region 2 Chinstrap Nests	989	79	16			
Statistical Analysis #7: Region 1 v. Region 2 Gentoo Nest Comparisons [b]						
Region 1 Gentoo Nests	116	96	64	-0.98926	124.736	0.16223
Region 2 Gentoo Nests	328	90	22			
Notes: [a] Includes all colony (congeneric and non-congeneric nests); [b] Excludes congeneric colony nests.						

7.2 Analysis & Discussion of the Objective 2 Results

The area-density objective incorporates two inter-connected investigations: firstly, to determine whether accurate *nest-to-nest distances* can be established for the species utilising the results from the population census studies (chapter 6); and, secondly, to establish whether accurate *density figures* (i.e. the number of nests per m^2) can be established based on census and area information, together with the knowledge accrued, not least the spatial distribution patterns exhibited by the species as determined within the first investigation.

7.2.1 Spatial Representation of Colonial Nest-to-Nest Distances

As is immediately evident from the graphical representation of the test colony at figures 7-3 (from QGIS spatial calculations), we can confidently state that the nest-to-nest distances found within this colony range between 50cm (orange colouring) and 100cm (yellow), with the other records being attributable to interference from either non-nest objects or to non-breeding individuals which are likely to be positioned on the outskirts of colonies. Such findings are largely repeated for all of the remaining colonies (figures 7-1 and 7-2) but with the nest-to-nest distance range being between 50cm to 125cm, which is of significance in informing the colony density discussion detailed later.

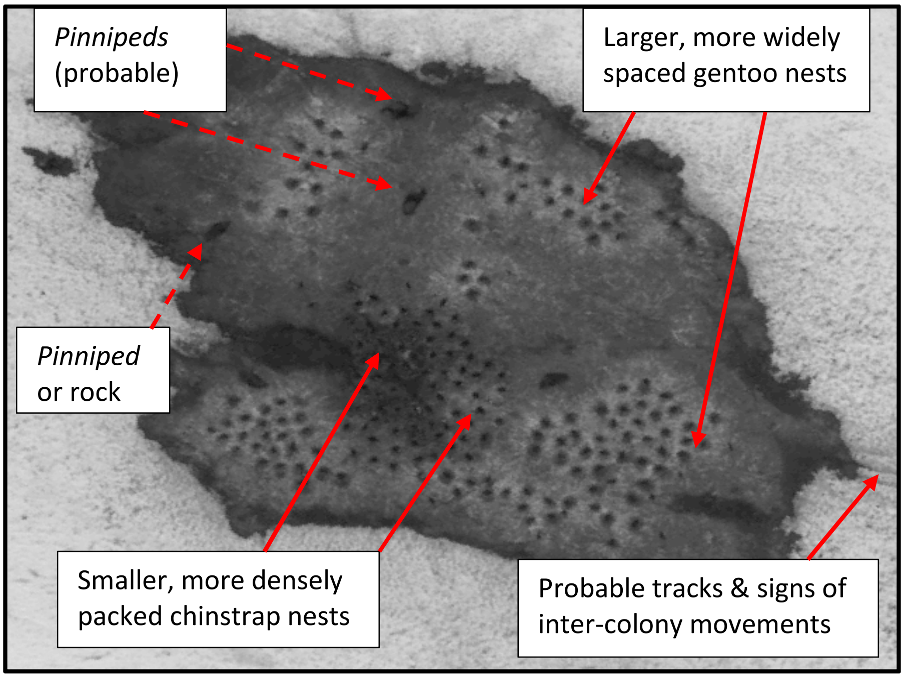
Of most interest and importance, however, in terms of adding credence to the methodologies and subsequent results, is that the average nest-to-nest distance for both species for all colonies within the rookery equates to **~1.02m** (table 7-1), or c. 7% more than the findings of the seminal work of Stonehouse (1975), with Stonehouse's records averaging 0.95m across the colonies he was examining. However, Storehouse's research calculations were based on the two species in isolation, an appreciation which led to the next stage of the research as described below.

7.2.2 Colonial Nest-to-Nest Distances for Each Pygoscelid Species

I next wished to determine whether it would be possible to apply the same approach/es to the congeneric colonies within the rookery, i.e., the eastern region colonies numbered 3, 5, 8, and 10; and the western colonies numbered 20 and 23.

Following advice from BAS and, again, the findings of Stonehouse (1975), the nests of the two congeneric *Pygoscelid* species are easily identifiable from the high-resolution imagery used for this research (figure 7-12):

Figure 7-12 Remotely Sensed Species Identification within a Congeneric Colony (Colony 23)



To determine the typical nest-to-nest distances for the two species within these congeneric colonies, all earlier steps were repeated, the results of which are summarized within table 7-2 and figures 7-6 to 7-9, with the congeneric sites illustrated within figures 7-10 and 7-11 (other than for Colony 8, which was not included as it was not possible to differentiate between the two species from the imagery).

The results when averaged out are remarkably similar to the (very) limited published data on the subject, principally from Stonehouse (1975), but also Davis *et al.* (1990), Woehler & Riddle (1998), and, Waluda *et al.* (2014).

The headline findings are:

- that the average distance recorded for chinstrap nests at the congeneric colonies was found to be 0.92m (as opposed to Stonehouse's result of *0.86m*) (table 7-2);
- that the average distance for the gentoo penguins at the same colonies was found to be 1.02m (Stonehouse's findings of *1.03m*) (table 7-2);
- that the mean nest-to-nest distance at all congeneric colonies was 0.76m with a standard deviation (σ) of 0.22m (table 7-4); and,
- that the mean nest-to-nest distances for all chinstrap colonies is 0.70m with a σ of 0.19m; whilst for gentoo colonies it is 0.91m with a σ of 0.29m (table 7-4).

Appendix 12 provides an example of the distance outputs together with the mean and standard deviation calculations.

These results are very positive and an indication of the real veracity of the methodologies developed. The findings are also as expected from an understanding of the literature, i.e., that chinstrap penguins tend to nest more closely together than gentoo penguins, with nest-to-nest distances as determined ranging from ~70 to 89cm, and 91 to 120cm, respectively, at non-congeneric colonies, equating to a mean differential range in terms of minimum and maximum nest-to-nest distances between the two species of c. 30% (minimum) to c. 35% (maximum).

Additionally, and as illustrated in figure 7-12, there is a clear distribution of the two species within congeneric colonies. As Stonehouse noted (1975) where "*two or more species of Pygoscelid penguins are cohabiting, a typical distribution over the ice-free area prevails, reflecting different habitat preferences and colonisation patterns*" (p.313).

Of particular note - and thought to have not been previously recorded - is that the mean nest-to-nest distances at congeneric sites, only, increases for both species, by c. 21% for the chinstrap penguin (from a mean of 76cm at non-congeneric sites, to 92cm at congeneric sites), and c. 12% for the gentoo (mean of 91cm to 102cm). Given the small sample size (5 colonies), further research is of course required: one inference, for example, may be that chinstrap penguins are less predisposed to nesting closer together with sympatric species but, equally, the actual nesting distances may be dictated by either topographical requirements and constrictions or, indeed, by sheer population numbers (the higher the number of breeding pairs and hence nests, the greater the packing densities – see below). Given that the chinstrap penguin typically prefers to nest on steeper ground to that of the gentoo, it may be assumed (to a degree) that the high inter-annual population fluctuations exhibited by both species may be the most controlling aspect.

7.2.3 Establishing Typical Colonial Nest Densities

Penguin colonies are known to maintain a relatively constant 'packing density' (Schwaller *et al.*, 1989) and thus provide the potential for definable whole-rookery population counts based on known densities and colony areas[38].

In lieu of this, the first step was to establish a more accurate understanding of the availability of suitable habitat within the rookery, which was approached via an examination of one of the congeneric colonies, Colony 5, as a pilot study. From ImageJ, the area of Colony 5, incorporating two sites, amounts to $562.445m^2$, giving a colonial nest density of one nest per $3.6m^2$ (based on records of 156 nests for the colony) (table 7-2). However, this area amounts to the total size of the colony and not necessarily the area that presents suitable nesting habitat. The master image was of sufficient resolution, however, to be able to more accurately determine the habitable areas, particularly in terms of substrate and topography and 'ornithogenic soil[39]', that have and continue to be populated, as illustrated in figure 7-13, below, and it is the limits of such areas that have been used to estimate the actual colony size in terms of suitable nesting habitats. For colony 5, this resulted in a revised colony size of ~ $324m^2$, giving a revised, average, nest density of one nest per $2.08m^2$ for the colony.

These calculations were made for all colonies and are represented in table 7-3. The mean nesting density (number of nests per m^2) for all colonies is 2.23, with a standard deviation of 1.19. Thus, the nominal nest density *range* for the Cape Shirreff rookery in its entirety is between ~ 1.04 and 3.42 nests per m^2. However, these figures do not bear into consideration a number of factors, not least the suitability of the topography for nesting, environmental vagaries, and the habitat requirements of individuals. Further development is required, particularly in terms of undertaking in-situ digital mapping of a rookery, although these initial findings may prove of use in terms of estimating populations from synoptic, remote, surveys and with regards to establishing carrying capacities for sites.

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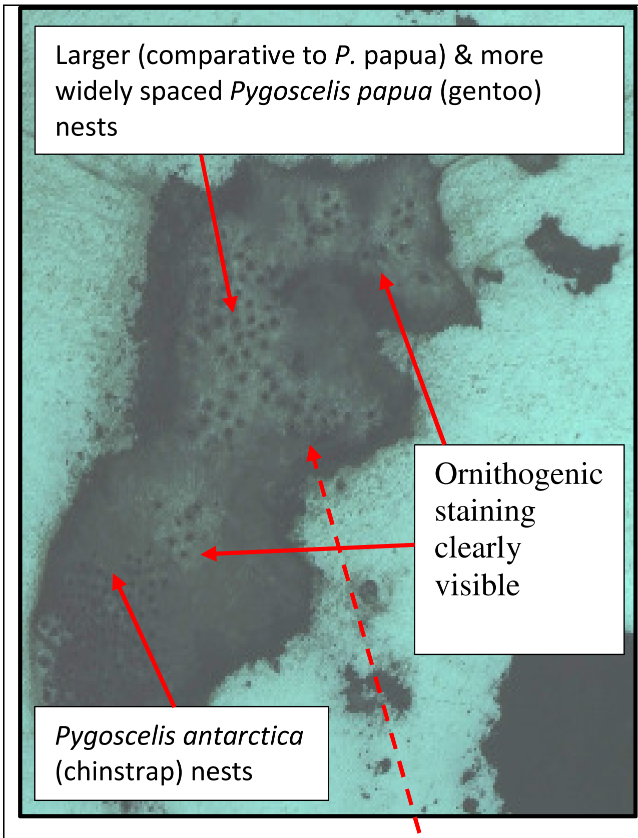
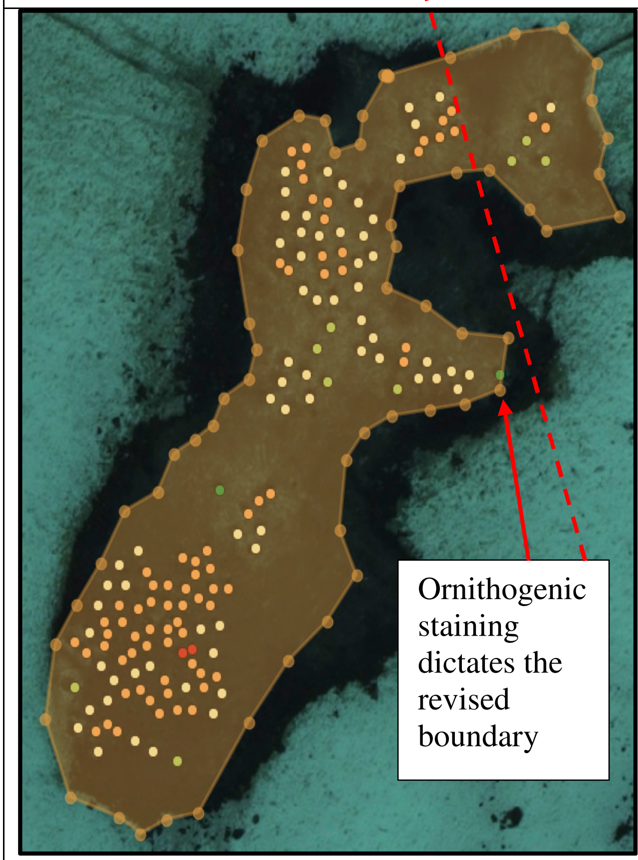
[38] Whilst as McNeill *et al.,* 2011, note, it is difficult to establish a reliable census count for a rookery unless a reliable relationship between nest count and a colony size via an assumed density preference per species is found.

[39] From Woehler & Riddle (1998), ornithogenic soil is formed by the accumulation of guano over time and can prove a very useful indicator of historic and contemporary colony extent.

Figure 7-13 Colony Area Comparisons

 	Pre-analysis boundary drawn via QGIS. Area = 562.445m^2. Nests are clearly identifiable and so is the historical colouration of the territory due to guano-staining over many years. It is the limit of this staining that, it is contended, delimits the actual colony boundary.
 	Post-analysis boundary drawn via QGIS. The revised boundary has been estimated based on the ornithogenic staining clearly shown above. Area = 324.086m^2.

The uncertainty, here, is further exacerbated by the inconsistent results noted in the limited literature published on the topic. For chinstrap penguins, Waluda e*t al.* (2014), determined an average nesting density (nests per m^2) of 0.53 +/- 0.33 (and 0.31 +/- 0.19 for gentoo penguins) at colonies at Signy Island, South Orkneys; *but* Naveen *et al.* (2012), recorded 1.5 chinstrap nests per m^2 at Deception Island (gentoos are not recorded). This latter study compares very well to the findings detailed here of an average of 1.69 chinstrap nests per m^2 for chinstrap-only colonies (table 7-5) (and 3.13 nest per m^2 for gentoo penguins). Given that Deception Island is, as with Cape Shirreff, within the South Shetland Islands archipelago, it may be confidently postulated that the distribution patterns noted by Naveen *et al.* will most closely match those from Cape Shirreff given that geographic locations can influence local perturbations in species' distribution patterns (amongst other indices).

However, without further research from which comparisons can be made, it is not possible to make any robust argument here, despite the seemingly encouraging similarity of findings with the work of Naveen *et al*. Irrespective of this, results will, it is contended, be affected by a number of factors, not least the location, the timing of survey, and surveying techniques but, primarily, due to errors in accurately defining colony boundaries. It is these factors rather than a deficiency in the methodology that is to blame for any errors.

A further note of caution is needed here in that the calculation of nest densities (and nest-to-nest distances) are also dependent on the quality of the image and the preciseness of the original manual counting procedure whereby each nest within an image was dotted with a colour in order to both count it and to gain coordinates information. Once the results had been compared to the master image, most of the nests appeared to be either within the central mass of a nest or within a pixel or two of the central mass, with a pixel equating to ~0.141m or 14cm. Errors are therefore to be expected but from a visual analysis, would seem to be within acceptable limits (c. +/- 10%). For those colonies where more considerable errors occurred, the whole exercise was repeated beginning to end until the results looked comparable to the master image.

7.2.4 Statistical Analysis

To test for the significance of differences between samples, Welch's t-test (for samples of different sizes with different variances) was applied. Also known as the 'independent sample' t-test, the Welch's t-test is a more reliable means than the standard 'Student's t-test' for assessing two unequal (or unpaired) samples[40].

From table 7-6, the p-values determined from five of the seven tests undertaken are almost infinitesimally small; this is not surprising as four of the five tests (analyses #1 to #4) compare chinstrap nests with those of gentoos, at varying spatial scales and it may be expected that the differences would be large given the information that has been gleaned earlier with regards to nest-to-nest distances and 'typical' nesting densities for the two species, together with their topographical requirements.

The fifth test (analysis #6) compared region 1 and 2 chinstrap nests and would have been expected to return a larger p-value, i.e. that the samples would be more similar. One reason for the difference may be the fact that for region 2, there are only two chinstrap-only colonies and one of these colonies, 29, accounts for 98% of the results (972 out of 989 nests) and that this may cause significant skewing within the results. Region 1, on the other hand, has five chinstrap-only colonies and exhibits a more equitable division of nests. The remaining two tests (analyses # 5 and 7) resulted in much larger p-values of ~0.01 and ~0.16, respectively, and with correspondingly smaller t-values. Thus, the congeneric colonies within the two regions (analysis #5) may be determined as being relatively similar to each other; whilst the region 1 and 2 non-congeneric gentoo nests (analysis #7) are clearly the most similar samples of those tested, further highlighted with a t-value of very close to 0.

Whilst accepting that some caution is required when interpreting p-value results, the results are broadly as expected - chinstrap nesting habitats differ from those of gentoos – but why the gentoos, here, appear to display more uniformity across the two regions than that of their congeners, the chinstraps, remains unclear. Further research is required on this in the future and with much larger sample sizes.

Chapter Synopsis

The calculations for the nest-to-nest distances for the variety of configurations tested are thus very encouraging and clearly highlight the exactitude of the approaches detailed within the preceding chapters. The area-density calculations, however, would appear to be either very accurate, being commensurate with one of the two previous research projects identified or, correspondingly, wholly inaccurate. The veracity of the area-density approach is not in

[40] http://uk.mathworks.com/help/stats/ttest2.html

question, but there remains a need for a ground-truthing element to the research in order to establish (and monitor) colony boundaries and, thus, to be able to produce more robust and verifiable results.

8.0 Conclusions & Recommendations

8.1 Analysis of Results & Discussion

Hypothesis: Proven or Otherwise?

The hypothesis posited at the beginning of the research was that *open-source* computer software may be used to automatically analyse remotely-sensed imagery to provide demographic results that accurately correlate with those from more traditional surveying approaches. To test this hypothesis, two research objectives were set, firstly to establish whether population census information could be acquired from such an approach; and, secondly, whether population densities in terms of nest distances and area-density relationships could be similarly established.

With regards to the first objective, all three approaches undertaken (manual, semi-automated, and quasi-automated counting), correlated very positively (in excess of a 95% accuracy for the rookery population as a whole) with the US AMLR field data for the 2013-14 season. Whilst the attempt at applying the most automated of the approaches (the quasi-automated approach) to count nests in one 'pass' for the whole rookery ultimately proved unsuccessful, the approach was highly efficacious when applied on a per-colony basis, providing for a mean accuracy of 96%. Further, the time taken to perform the quasi-automated investigations was less than half that taken by the manual approach (~0.45 seconds per identified nest compared to ~1.02 seconds per manual count), albeit lessons learnt from the earlier stages would doubtless of aided the process such that the timings are not robustly defended here. However, it would appear that the more automated approach is most suitable to larger colonies but that for colonies of, say, less than 1,000 nests, manual or semi-automated counting remain (marginally) more suitable solutions.

With regards to the second objective, the mean calculated nest-to-nest distance within the rookery of 1.02m correlates very closely (c. + 7%) with the results from Stonehouse's seminal work (in 1975); whilst the calculated chinstrap nest density within non-congeneric colonies of 1.69 nests per m^2 corresponds very closely with the findings of Naveen *et al.* (2012) at 1.5 nests per m^2. However, for both investigations, the distinct paucity of data is of concern, for example in terms of the absence of comparable gentoo data; whilst without accurate colonial boundaries, the nesting densities determined are reasonable, informed, assumptions, only.

Of further significance – and, it is thought, previously unheralded – is that the mean nest-to-nest distances for both species at congeneric colonies increase markedly (by c. 21% and 12% for the chinstrap and gentoo, respectively) when compared to colonies with only one species present. This may prove to be a particularly interesting finding but it is as yet unclear as to why such pronounced differences should occur, or whether the readings are simply anomalous or are repeated at other colonies and during other seasons. It may be the case that chinstraps are simply the more solitary neighbour of the two species, but more likely that there are a number of reasons, not least in terms of the number of breeding pairs present, the availability of suitable habitat and topographic preferences. As with the above, further experimentation is required.

The results cultivate a very real confidence in the veracity of the approaches taken. It can therefore be stated with some certainty that open-source applications *can* be very successfully used for the research in question and that the *hypothesis is proven*, but with one caveat - that the results are based on one rookery, and from one season, only, and further, repeatable, testing is required in order to draw more robust conclusions.

Climate Change

This research was initiated from a desire to examine the usefulness of applying remote sensing technologies and techniques to aid species conservation (particularly higher-trophic level predators) in lieu of the spectre of climate change within the Antarctic and Southern Ocean.

As Trivelpiece *et al.* (2011) note "*there is now overwhelming evidence to confirm significant declines…in chinstrap penguin populations*" (p. 7,627)[41], and as witnessed at Cape Shirreff, with the US AMLR recording a precipitous decline in numbers of the species of c. 38.5% over the three seasons preceding the 2013-14 season, and with only very moderate (c. 0.6%) increases in gentoos over the same period. Indeed, whilst the two species do exhibit inter-annual variations in populations, these are believed to be becoming more pronounced due to

[41] Whilst, Clucas *et al.* (2014) further state that "*climate change produces 'winners', species that benefit, and 'losers', species that decline or become extinct…[with] Pygoscelid penguins, sensitive indicators of environmental change, already showing responses to current climate warming*" (p.1).

changes in regional temperatures (Pistorius *et al.*, 2010), such that 'normal' population fluctuations are being significantly modified.

The gentoo penguin is believed to be more resilient to change due to a variety of factors, not least its wider geographic range, a more varied diet, and greater phenotypic plasticity (*inter alia:* Korczak-Abshire *et al.,* 2013; Pena *et al.*, 2014); with the chinstrap being more at risk of the two with reduced population distribution, a lower reproduction rate, and a dependence on Antarctic krill (*Euphausia superba*), and suggesting that the downward trajectory in numbers will continue. It is therefore essential that we systematically monitor the impact on *Pygoscelid* species and other indicator species so as to determine not only their own conservation status but also to gain an appreciation of the health of the wider marine ecosystem (*inter alia:* Trathan, 2004; McMahon *et al.*, 2014).

The threats posed by climate change must not be underestimated. Irrespective of the important arguments surrounding causation factors which are not pertinent to this thesis, it is clear that significant warming is already being experienced within the region, with corresponding ecosystem and species-level effects. Aligned threats may include the influx of invasive species and an increase in extreme climatic events with resultant community-level influences (Lescroel *et al.,* 2014).

8.2 Lessons Learnt & Recommendations for Future Research

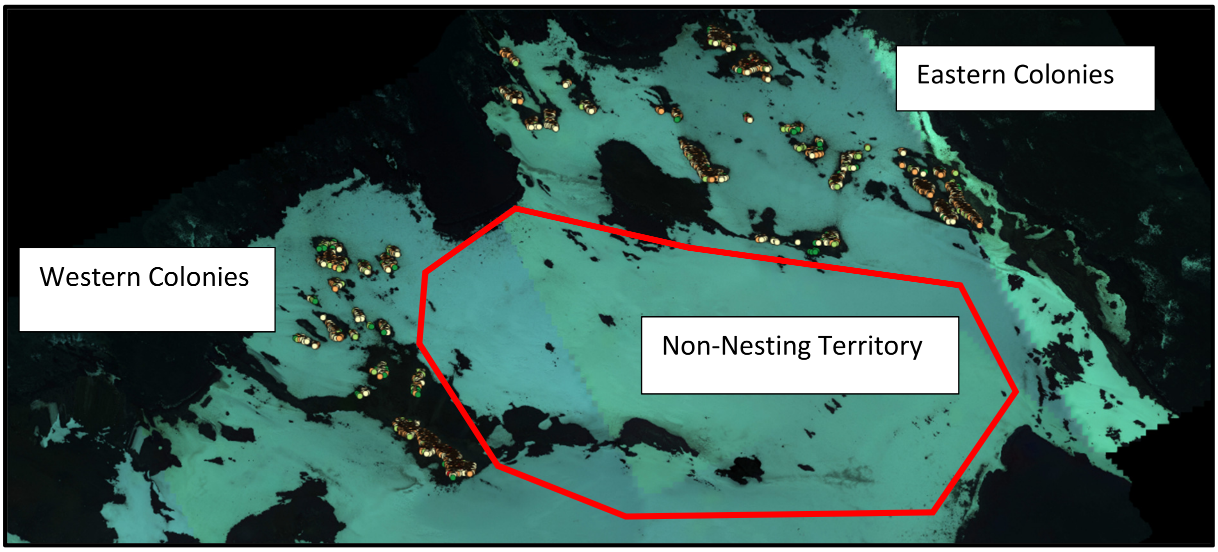
Whilst the approaches described here were successfully implemented for the purposes designed, it is clear that additional testing is required and should incorporate all three *Pygoscelid* species together with data from colonies found throughout their respective geographical ranges to determine any species or location-led differences and influences.

Further, a database of colony and rookery sizes (area) should be established from which changes over time can be established. In the first instance, this would require in-situ accurate mapping of the boundaries employing a digital mapping system, much as described by Waluda *et al.* (2014), incorporating a hand-held geographical positioning system (GPS) and mobile GIS software. Protocols should be established with regards to establishing uniform definitions of colony boundaries, with the suggestion here that a 1 metre buffer zone (or other pre-determined distance) be added from the colony edge (typically, the furthest breeding/nesting individual/s from the central assemblage of nests that compose a colony), in order to minimize potential difficulties in establishing a meaningful boundary, but that non-breeding individuals should not be included within these calculations (although trend estimates of the proportion of non-breeders to breeders within a colony would also be of interest, such as in terms of assessing any perceived impacts of warming on the ability of individuals to form breeding pairs).

The accurate measurement of colonial boundaries are clearly key to the establishment of verifiable nest densities but as has already been discussed, in-situ surveys within the region are both expensive and logistically difficult. It may be the case, however, that such ground surveys are only required on an infrequent basis, perhaps every five or ten years, with more remote investigations undertaken in the interim.

An additional note of interest that emerged from the research is that within the total rookery area of c. 46 ha., a central belt of c. 11 ha. of land exists which does not contain evidence of either historical or contemporary nesting, as very approximately shown in figure 8-1.

Figure 8-1 Cape Shirreff Rookery 'Empty Quarter'



From an analysis of the image, it would seem that at least part of this area would provide habitable areas for both species but it must be concluded that the topography is simply not deemed suitable by the species or, perhaps, that colonies situated here would be too far from the foraging grounds on which the species depend for their prey. As with the apparent increase in nest-to-nest distances displayed by the species within congeneric colonies, this appears to be a new finding and may be of importance to future conservation initiatives, with the finding posing intriguing questions, such as: what are the average distances of colonies from foraging grounds?; what are the maximum distances travelled by individuals on foraging trips (land and sea)?; does distance travelled affect recruitment, breeding frequency and success?; and, can any relationship/s be measured? Knowledge of all of which would allow for more accurate census measurements over time (Baylis *et al.,* 2012).

Further, and particularly salient to Cape Shirreff, is a requirement to measure the prey populations, too. The two species are known to be highly dependent on Antarctic krill, here, but their foraging ranges overlap significantly with the commercial fisheries in the region (Penhale & Marchant, 2010) and implications of this over time requires further investigation.

Above all, it is to be hoped that the approaches and lessons learnt will contribute to a greater collective knowledge of the genus in the future, thereby aiding the conservation of the species. It is apt, however, to leave the last remark to Stonehouse who memorably noted in 1975 "*I particularly regret the absence…of long-term population studies*" (p.12).

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Appendices

Appendix 1.0 Acronyms, Abbreviations, & Definitions

Acronym, Abbreviation, Concept	Definition
ACT	The Antarctic circumpolar trough is located between approximately 60°S and 65°S, and is a zone of low pressure that contains variable winds that blow from the west to the east. Within this region, ferocious storm systems gather warm, moist, air from mid-latitude areas and export them polewards, resulting in extensive cloud systems and prolonged precipitation. These pronounced storms typically last for a few days before clearing but after a short period of more temperate weather, further storms typically emerge.
Aptenodytes forsteri	Emperor penguin.
ASL	Amundsen Sea Low.
ASPA	Antarctic Specially Protected Area. An area of outstanding environmental, scientific, historic, aesthetic, or wilderness value.
Biogeography	The "*geographical distribution of plants and animals*" (Concise Oxford English Dictionary, 11th Edition, 2004).
Biome	An ecosystem that is characterized by distinctive plant and animal species and influenced by regional climatic conditions.
CCAMLR	The Commission for the Conservation of Antarctic Marine Living Resources.
CCAMLR CEMP	The Commission for the Conservation of Antarctic Marine Living Resources' Ecosystem Monitoring Program.
Colony	The discrete group of nesting birds to be found within a rookery (Stonehouse, 1975). See also 'sub-colony' below.
Congeneric	An animal or plant as the same genus as another.
DEM	Digital Elevation Model.
ENSO	El Niño Southern Oscillation (ENSO).
Epontic species	Species that live on the underside of sea ice, such as Antarctic krill (*Euphausia superba*).
Euphausia superba	Antarctic krill.
Fecundity	The number of chicks produced per breeding pair.
GIS	Geographical Information System.
IBA	Important Bird and Biodiversity Area.
ICSU	International Council for Science
Incubation period	The interval between the beginning of incubation and the final emergence of the chick from its shell (Gwynn, 1953).
IUCN	International Union for the Conservation of Nature.
Metapopulation	A demographically related group of colonies isolated from others (Ainley, 2002).
Monomorphic	A species showing "*little or no variation in morphology or phenotype*" (Oxford English Dictionary, 11th Edition, 2004).

Appendix 1.0 Acronyms, Abbreviations, & Definitions (cont.)

Acronym, Abbreviation, Concept	Definition
NOAA	National Oceanic and Atmospheric Administration.
Orthophoto & Ortho-rectify	Orthorectification of imagery takes into account the variations in scale (such as geometrical distortion) caused by the topographic relief of a site. It requires a knowledge of both the topographic relief and the viewing geometry and produces an 'orthophoto' i.e., a digital image that has had any geometrical distortion removed, providing an accurate representation of the land surface.
Pansharpening	In essence, this involves the combining of a high-resolution panchromatic image with a somewhat lower resolution multispectral image to deliver a high-resolution colour image.
Phenotype	The observable characteristics of an organism (as resulting from its interaction with the environment).
Phenotypic Plasticity	The ability of an organism to "*express different phenotypes depending on the environment*" (Lescroel *et al*., 2014).
Pinniped	Seals.
Pygoscelis or *Pygoscelid*	The 'genus' of the brush-tailed penguins comprising the Adélie, chinstrap and gentoo penguins.
Pygoscelis adeliae	Adélie penguin
Pygoscelis antarctica	Chinstrap penguin.
Pygoscelis papua	Gentoo penguin.
Rookery	The full assembly of birds in a particular location; i.e. for the purposes of this research, Cape Shirreff is deemed to be the rookery. (Stonehouse, 1974).
SAM	Southern Annular Mode.
SCAR	Scientific Committee on Antarctic Research (part of the International Council for Science).
Sphenisciformes	The 'order' of penguins. The higher taxonomic classification levels for penguins are: Kingdom: *Animalia*; Phylum: *Vertebrata*; Class: *Aves*. Following these, they form the order *Sphenisciformes* which comprises one family, *Spheniscidae* ('the penguins'). The family *Spheniscidae* in turn comprises six genera (of which, the 'brush-tailed' or *Pygoscelids* are one genus), and, it is generally accepted, 17 species, although there is considerable debate in some quarters on the classification of sub-species.
SSSI	Site of Special Scientific Interest.
SST	Sea Surface Temperature.

Acronym, Abbreviation, Concept	Definition
Sub-Colony	Outlying individuals located a discrete distance from the colony.
Sympatric	Occurring in the same or overlapping territories. Indeed, all three species of the genus may on occasions be found within the same rookery (Stonehouse, 1975), but not within the Cape Shirreff rookery, where the Adélie penguin does not currently breed.
US AMLR	United States Antarctic Marine Living Resources Program.
WAP	Western Antarctic Peninsula.

Appendix 2.0 Process Flow-Diagrams: Screen-Prints

Table A Semi-Automated Approach: Process Steps with Example Screen Prints

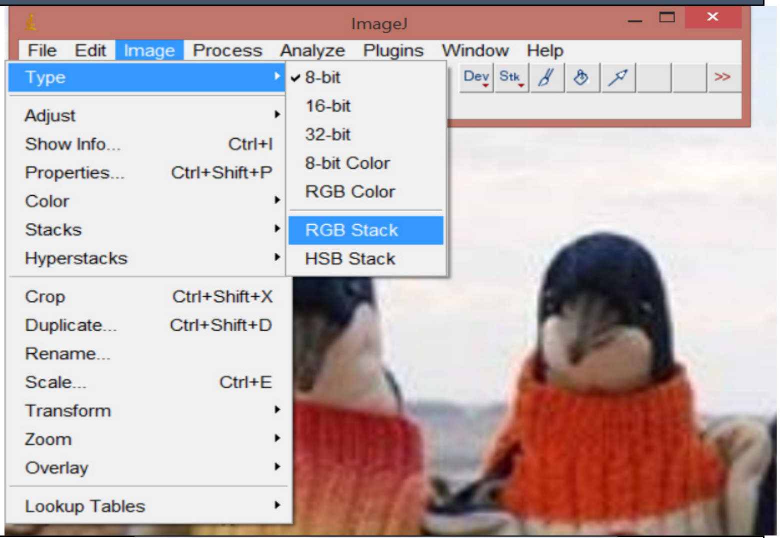
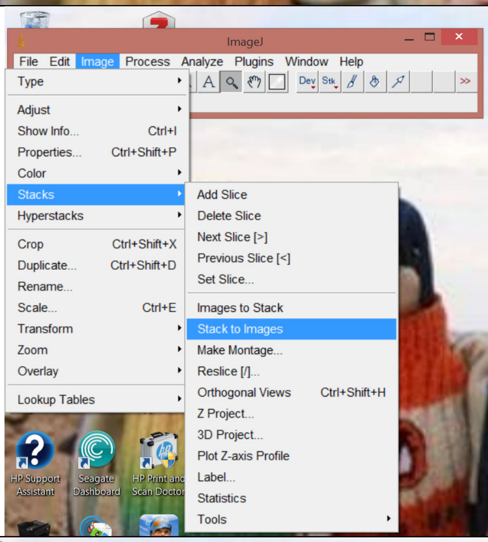
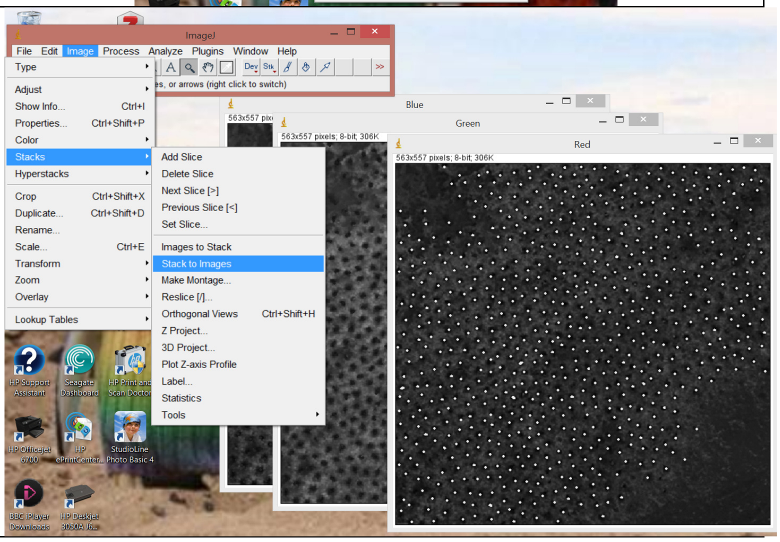
Step	Description	Example Screen Print
2a	Altering the image appearance [Image-Type-RGB-Colour-RGB Stack]	
2b	Altering the image appearance [Image-Stack-Stack to Images]	
2c	Altering the image appearance [Delete the blue & green windows]	

Table A (cont.) Semi-Automated Approach: Process Steps with Example Screen Prints

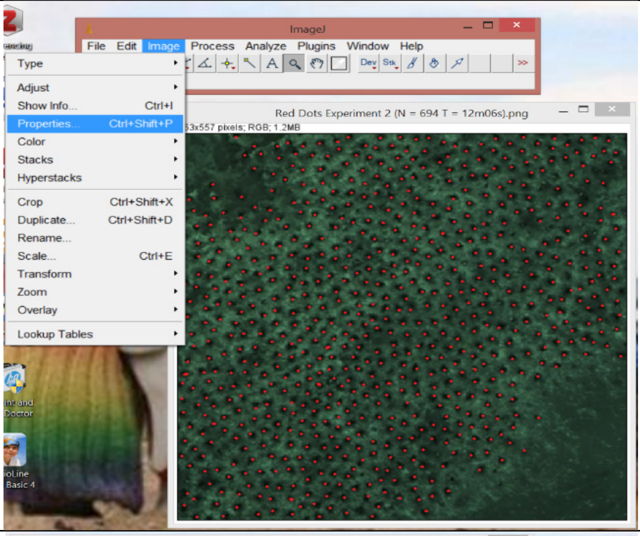
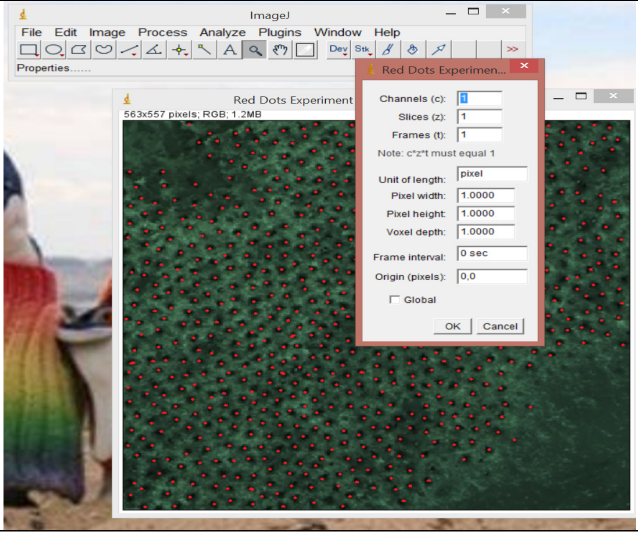
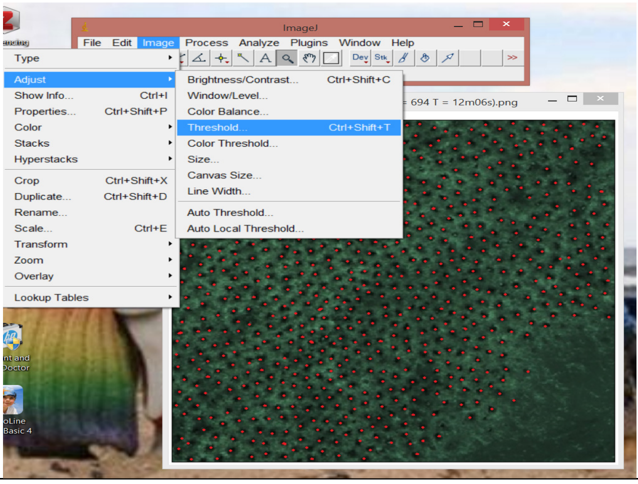
Step	Description	Example Screen Print
3a	Establishing the image properties [Image – Properties]	
3b	Adjusting the pixel height & width	
4	Adjusting the image threshold [Image-Adjust-Threshold]	

Table A (cont.) Semi-Automated Approach: Process Steps with Example Screen Prints

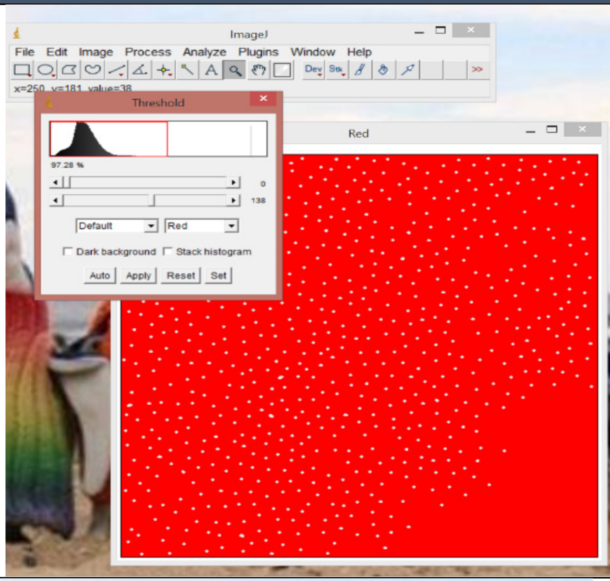
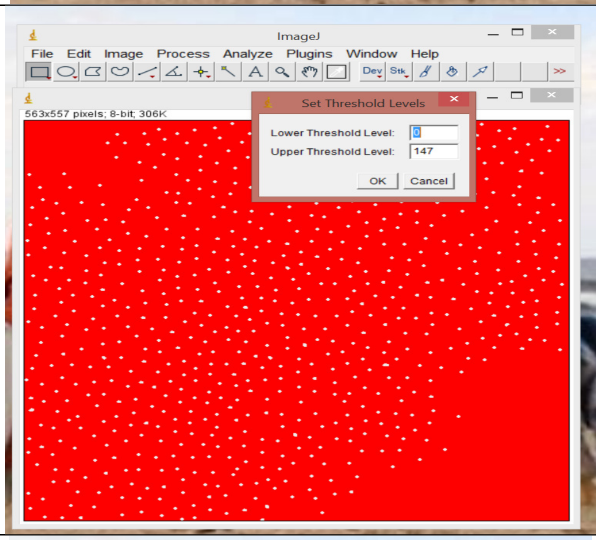
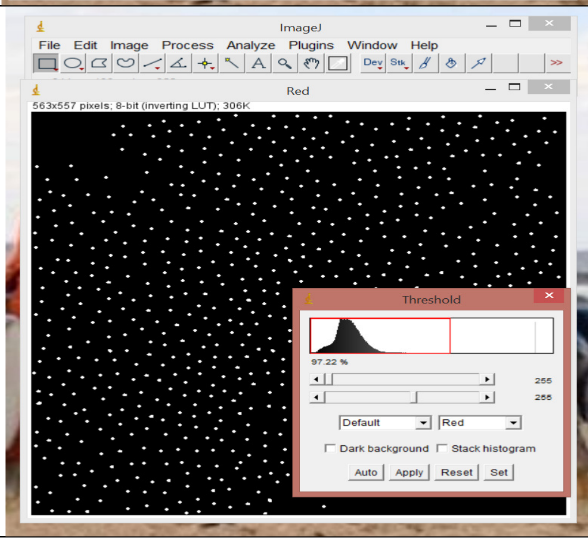
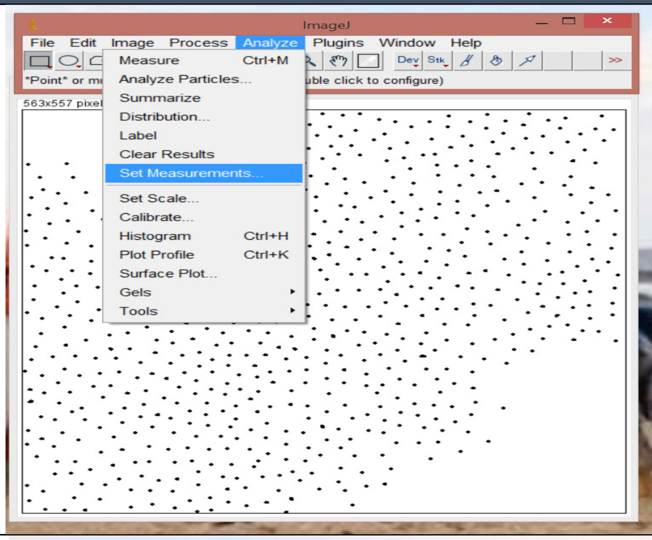
Step	Description	Example Screen Print
4a	Adjusting the threshold	
4b	Set minimum & maximum threshold	
4c	Apply threshold	

Table A (cont.) Semi-Automated Approach: Process Steps with Example Screen Prints

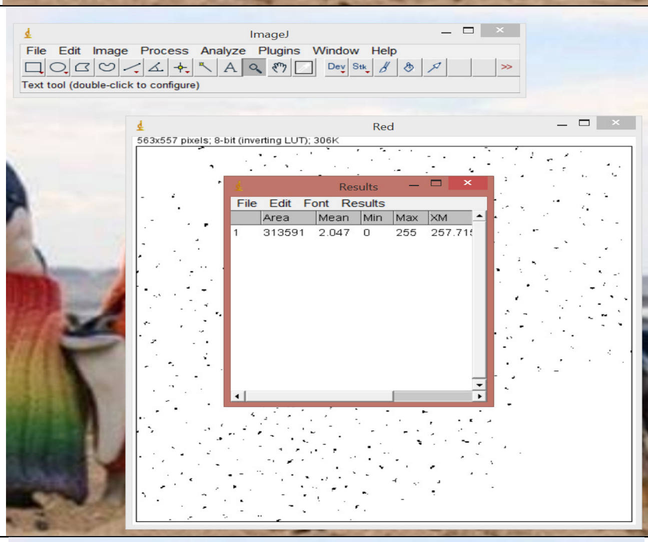
<table>
<tr><th>Step</th><th>Description</th><th>Example Screen Print</th></tr>
<tr><td>5 &
5a</td><td>Setting the measurements

[Analyze – Set Measurements]

Choose ‘area’ & ‘centre of mass’ to start with.</td><td>

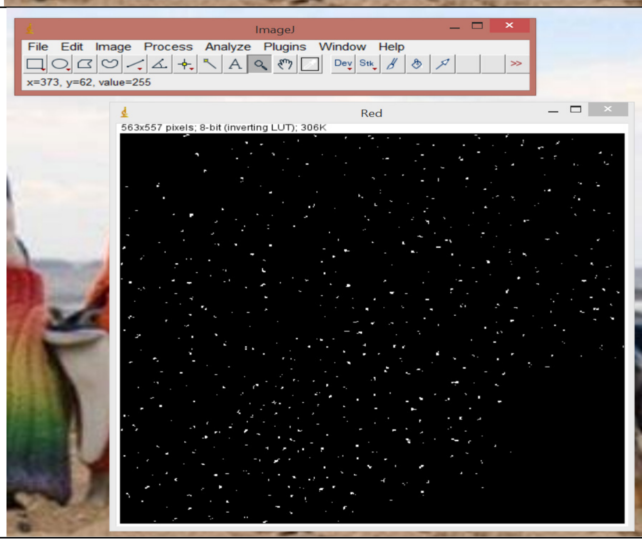


</td></tr>
<tr><td>5b</td><td>Analyze – Measure – Area</td><td>



</td></tr>
<tr><td>5c</td><td>Invert image

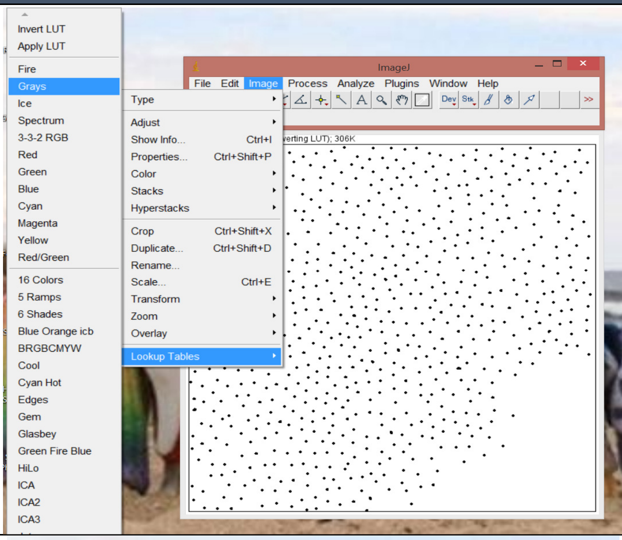
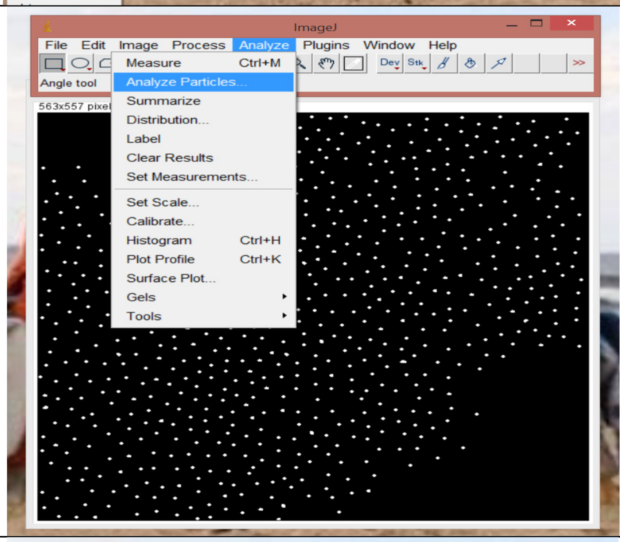
[Edit-Invert]</td><td>



</td></tr>
</table>

Table A (cont.) Semi-Automated Approach: Process Steps with Example Screen Prints

<table>
<tr><th>Step</th><th>Description</th><th>Example Screen Print</th></tr>
<tr><td>6</td><td>Select greyscales

[Image-Lookup Tables-Grays]</td><td>
</td></tr>
<tr><td>7</td><td>Analyze-Particles</td><td>
</td></tr>
<tr><td>7a & 7b</td><td>‘Show outlines’

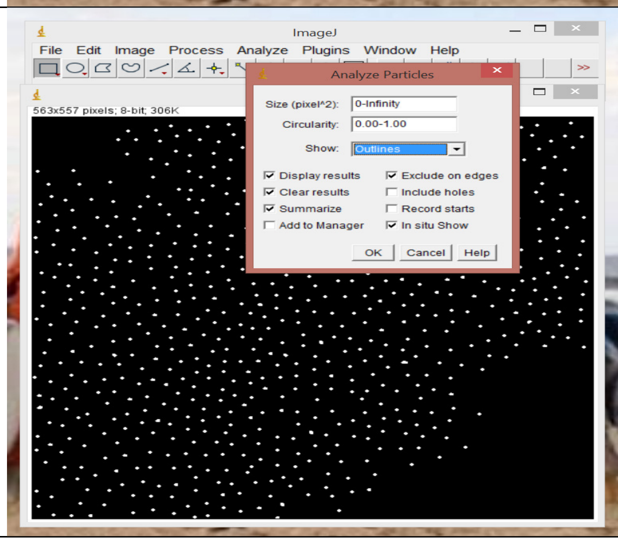
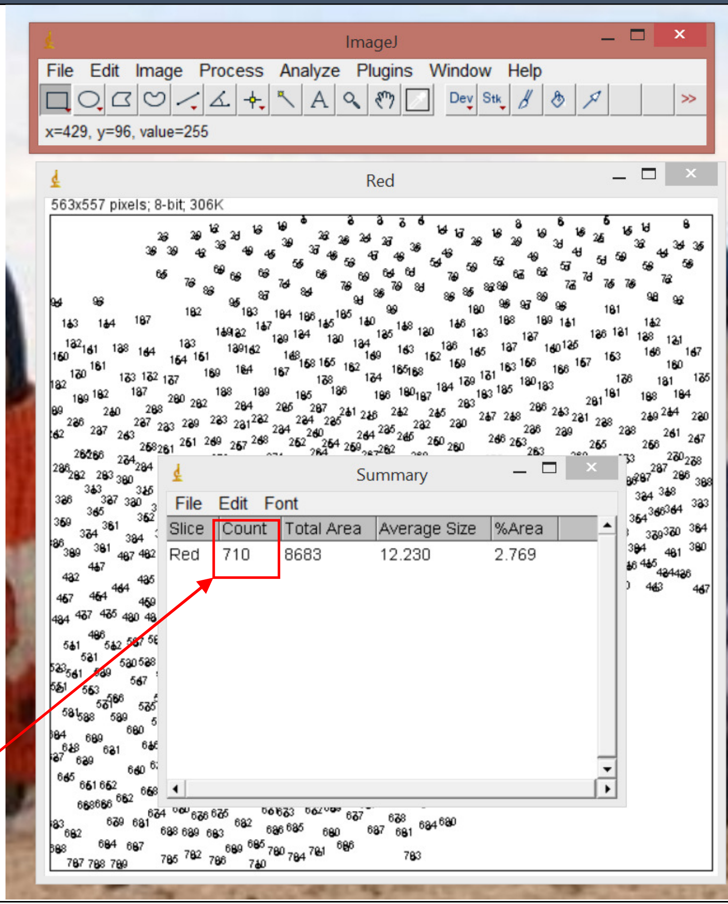
& click ‘ok’</td><td>
</td></tr>
</table>

Table A (cont.) Semi-Automated Approach: Process Steps with Example Screen Prints

Step	Description	Example Screen Print
8	Software analysis output Number of objects identified	
9	Typical spreadsheet output example (for statistical analysis)	

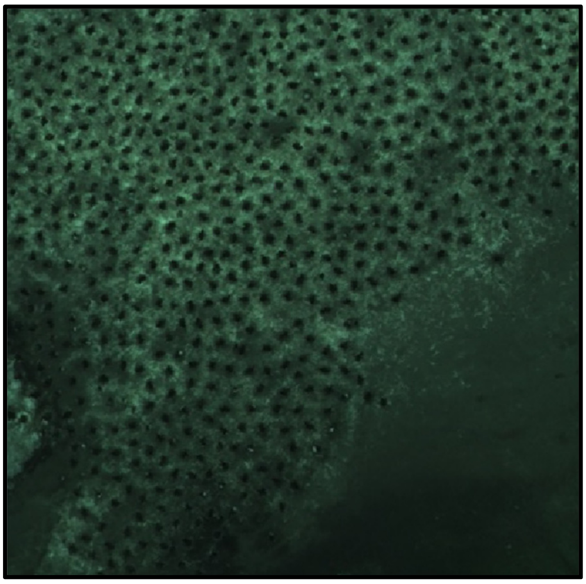
	Area	Mean	Min	Max	XM	YM	Median
1	5	255	255	255	217.7	2.7	255
2	3	255	255	255	397.5	1.5	255
3	4	255	255	255	278.25	2.75	255
4	5	255	255	255	431.9	3.3	255
5	4	255	255	255	251.75	5.25	255
6	5	255	255	255	281.7	6.1	255
7	2	255	255	255	299	5.5	255
8	2	255	255	255	312.5	6	255
9	3	255	255	255	401.167	5.833	255
10	1	255	255	255	505.5	7.5	255

Appendix 3.0 Test Outputs

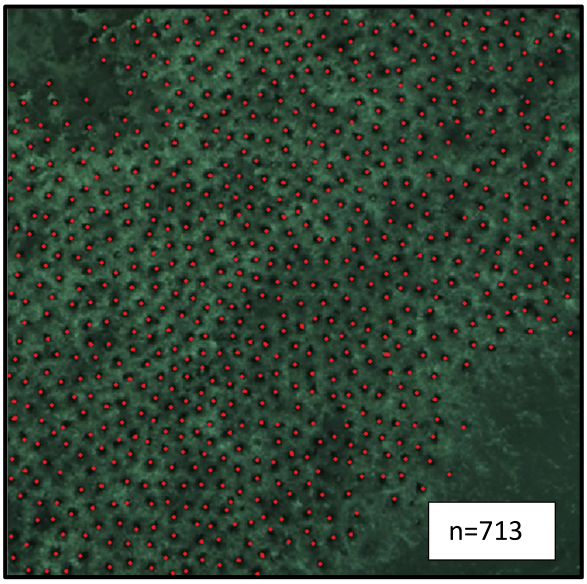
Figures A to D, provide the salient outputs from each of the objective 1 methodological approaches adopted for the four test sites, and as described in chapter 5.

Figure A Test Grid #1: Outputs from the Three Counting Approaches

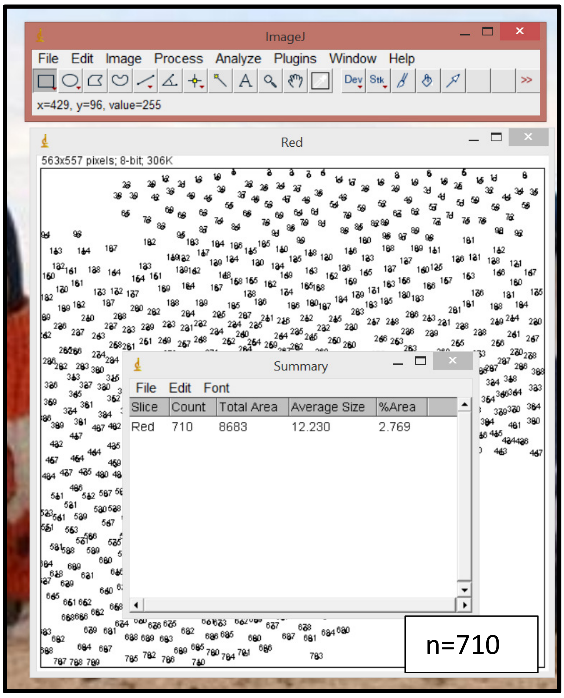
Blank



Manual Counting Output



Semi-Automated Counting Output



Quasi-Automated Counting Output

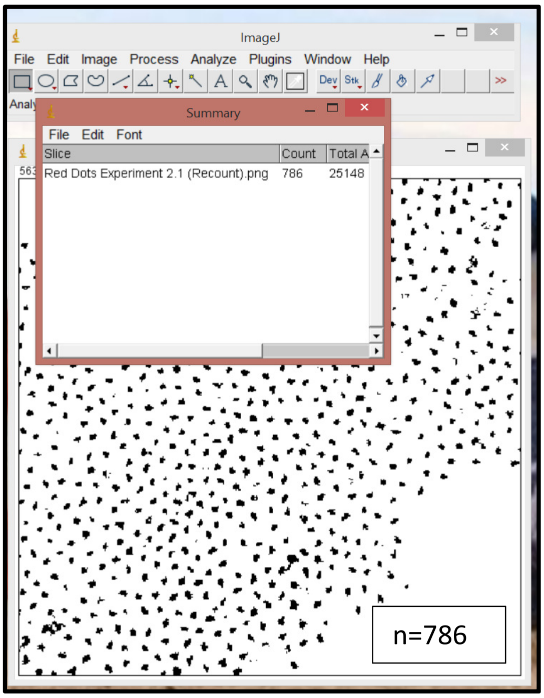
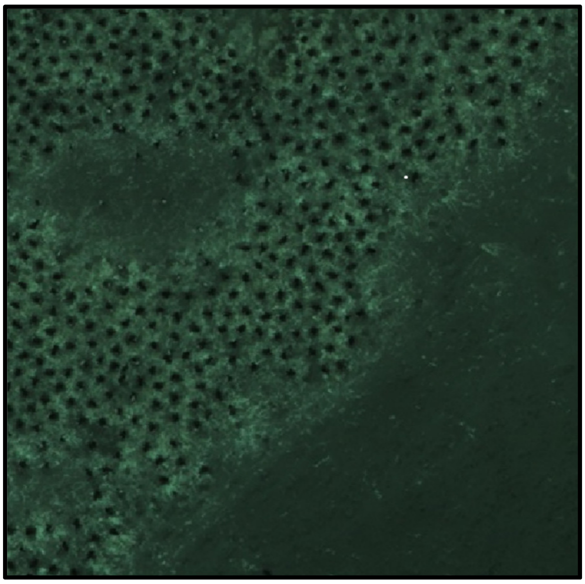
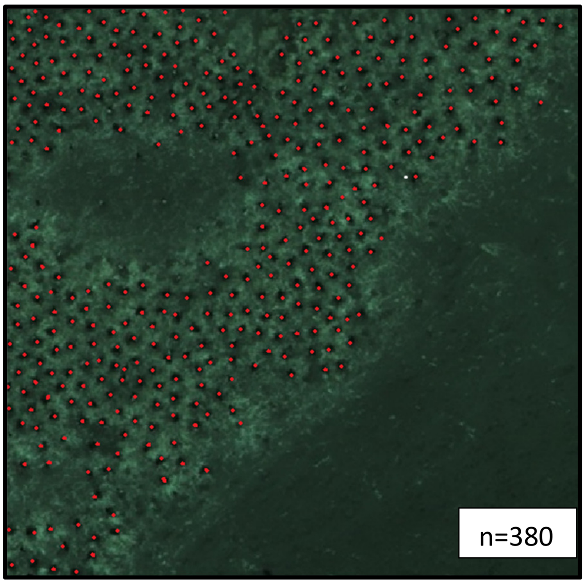


Figure B Test Grid #2: Outputs from the Three Counting Approaches

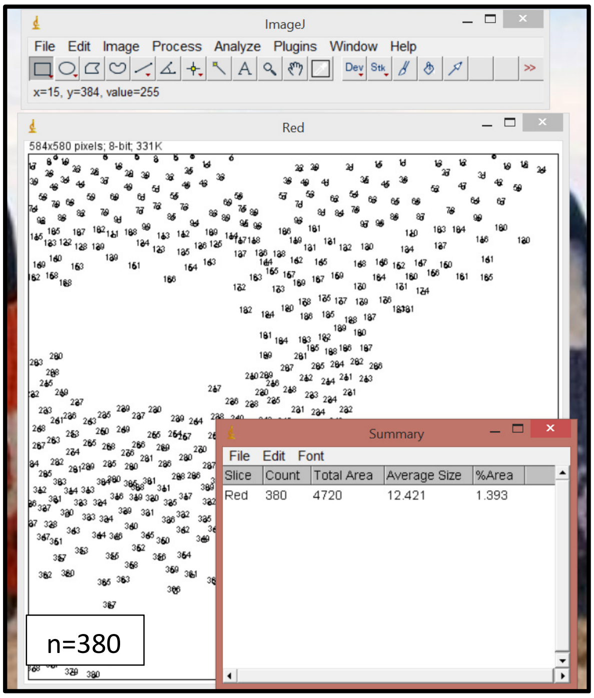
Blank



Manual Counting Output



Semi-Automated Counting Output



Quasi-Automated Counting Output

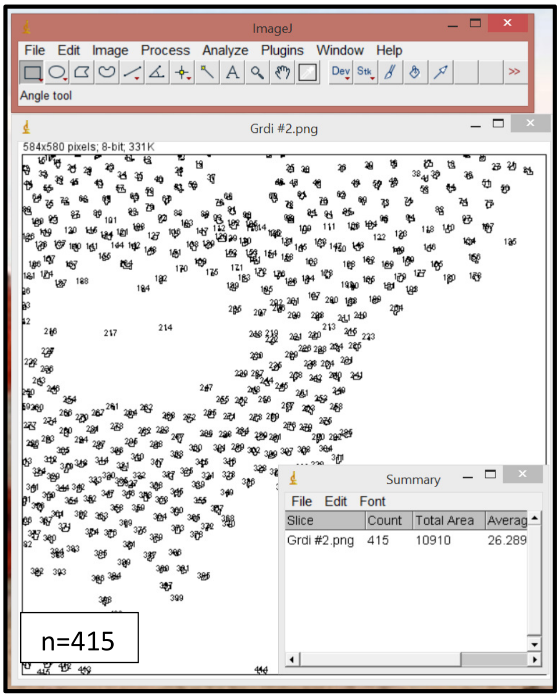
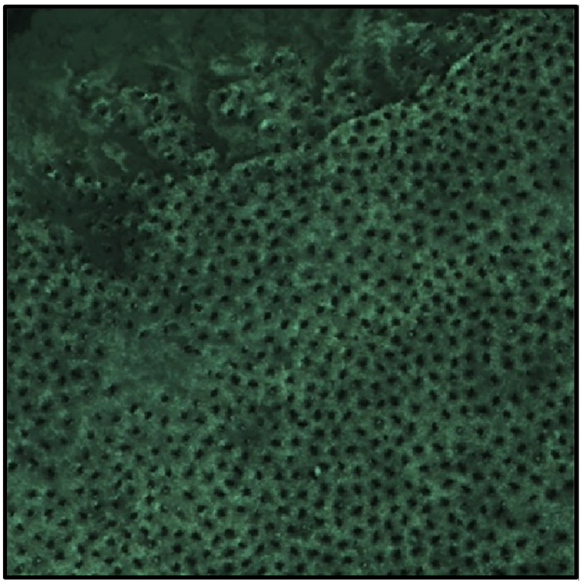
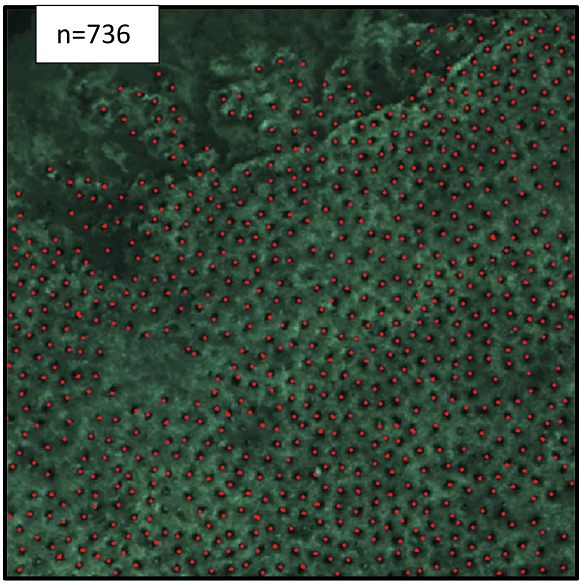


Figure C Test Grid #3: Outputs from the Three Counting Approaches

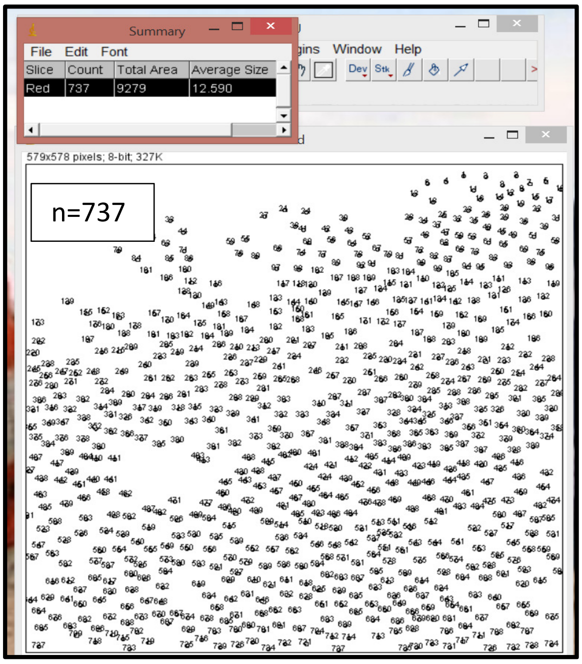
Blank



Manual Counting Output



Semi-Automated Counting Output



Quasi-Automated Counting Output

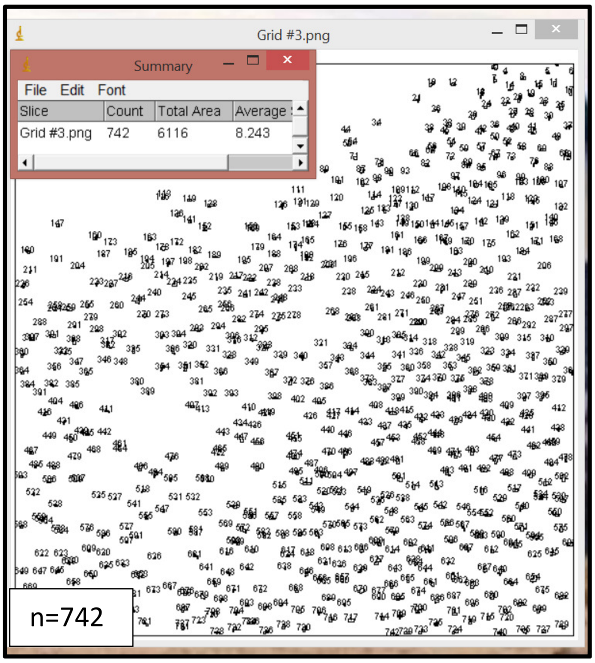
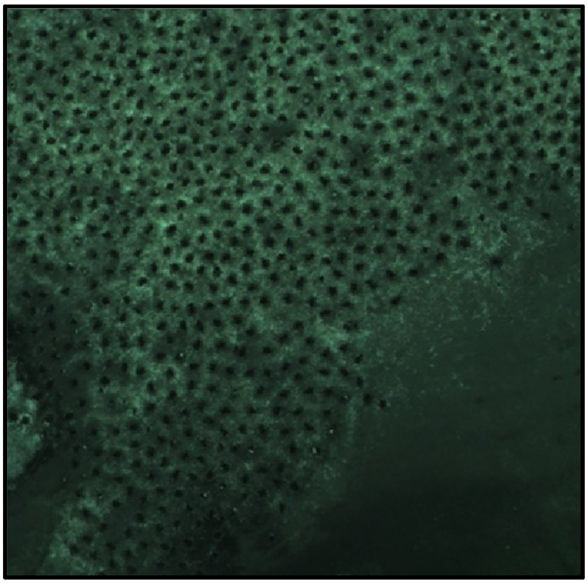
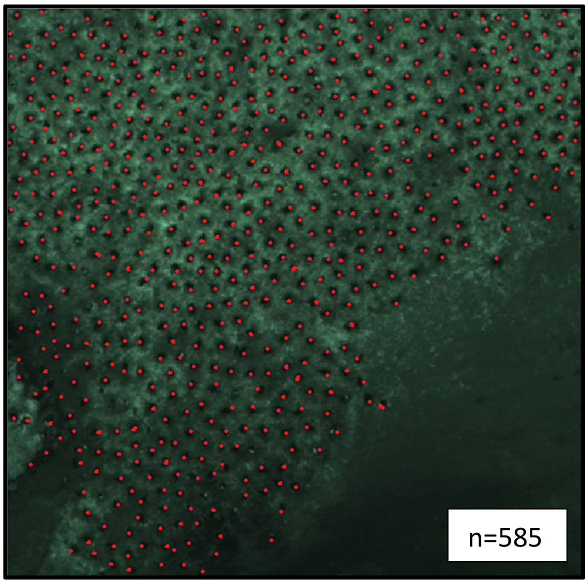


Figure D Test Grid #4: Outputs from the Three Counting Approaches

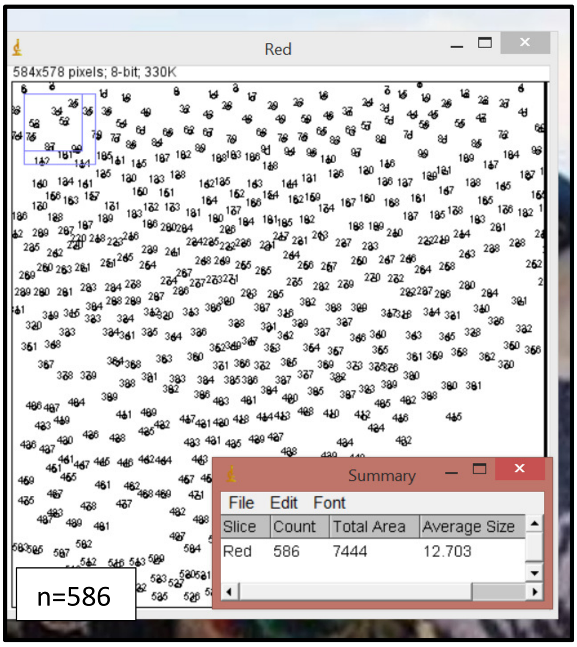
Blank



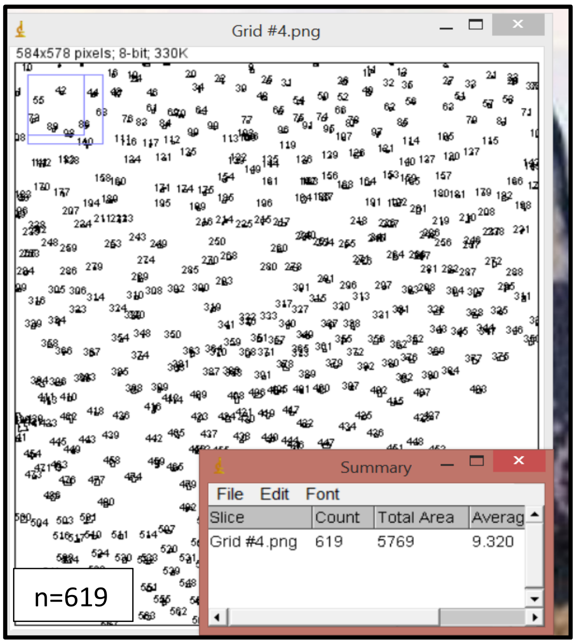
Manual Counting Output



Semi-Automated Counting Output



Quasi-Automated Counting Output



Appendix 4.0 Example Raw Data from Test Grid #1

Note: the column labels and the grid references were added once the data had been exported to MS Excel. The actual raw data runs to18 pages, the below is therefore just a snapshot of the data and for illustrative purposes, only.

Number	Area	X Coordinates	Y Coordinates	Grid Ref. 'x'	Grid Ref. 'y'
34	1	76.5	17.5	626506.7932	301578.4285
86	1	528.5	52.5	626546.9308	301575.2855
15	2	358.5	3	626531.8348	301579.7306
46	2	72	24.5	626506.3936	301577.7999
81	2	53.5	50	626504.7508	301575.51
299	3	562.5	195.5	626549.95	301562.4441
380	3	224.5	245.5	626519.9356	301557.9541
71	37	359.662	46.743	626531.938	301575.8025
78	37	180.473	51.527	626516.026	301575.3729
135	37	46.284	92.581	626504.11	301571.6862
545	38	451.053	350.474	626540.0535	301548.5274
560	38	150.763	361.895	626513.3878	301547.5018
587	38	145.421	383.395	626512.9134	301545.5711
590	38	421.5	384.105	626537.4292	301545.5074
601	38	286.395	391.184	626525.4319	301544.8717
610	38	5.421	403.921	626500.4814	301543.7279
649	38	30.526	429.579	626502.7107	301541.4238
652	38	154.737	432.737	626513.7406	301541.1402
684	38	347.816	461.316	626530.8861	301538.5738
697	38	133.921	468.974	626511.8922	301537.8861
751	38	77.711	519.316	626506.9007	301533.3654
45	39	501.346	25.756	626544.5195	301577.6871
174	39	276.09	121.064	626524.5168	301569.1285
245	39	252.962	167.269	626522.463	301564.9792
304	39	26.603	202.885	626502.3623	301561.7809
357	39	80.628	234.269	626507.1598	301558.9626
385	39	182.474	250.244	626516.2037	301557.5281
417	39	94.346	271.731	626508.3779	301555.5986
462	39	416.064	300.5	626536.9465	301553.0151
464	39	172.269	300.038	626515.2975	301553.0566
508	39	239.013	327.603	626521.2244	301550.5813
570	39	106.885	371.269	626509.4914	301546.66

Number	Area	X Coordinates	Y Coordinates	Grid Ref. 'x'	Grid Ref. 'y'
141	44	319.909	100.182	626528.4079	301571.0037
147	44	406.841	103	626536.1275	301570.7506
212	44	405.909	143.932	626536.0447	301567.0749
290	44	466.091	193.955	626541.3889	301562.5828
342	52	489.365	227.25	626543.4556	301559.593
674	52	182.615	451.808	626516.2162	301539.4276
728	52	294.596	496.385	626526.1601	301535.4246
431	53	405.84	277.255	626536.0386	301555.1025
511	53	255.085	328.972	626522.6515	301550.4583
632	53	216.972	417.198	626519.2671	301542.5356
634	53	319.972	419.104	626528.4135	301542.3645
706	53	334.896	477.575	626529.7388	301537.1138
709	53	140.708	484.896	626512.4949	301536.4563
586	54	319.926	381.759	626528.4094	301545.718
698	54	173.352	469.556	626515.3937	301537.8339
737	54	111	505.241	626509.8568	301534.6294
118	55	477.591	80.7	626542.4101	301572.7531
122	55	216.773	84.736	626519.2494	301572.3907
378	55	382.773	246.118	626533.9902	301557.8986
630	55	123.845	418.118	626510.9974	301542.453
646	55	335.5	427.064	626529.7924	301541.6497
678	55	201.173	453.282	626517.8642	301539.2953
753	55	188.918	521.155	626516.7759	301533.2003
778	55	100.427	549.718	626508.9179	301530.6353
549	56	193.089	354.964	626517.1463	301548.1242
564	56	248.357	363.964	626522.0541	301547.316
770	56	7.357	540.071	626500.6533	301531.5016
783	56	245	553.107	626521.756	301530.331
323	57	176.921	213.465	626515.7106	301560.8308
607	57	74.763	398.921	626506.639	301544.1769
671	57	263.079	449.079	626523.3614	301539.6727
767	57	174.518	535.816	626515.4972	301531.8837
680	58	308.948	455.948	626527.4346	301539.0559
691	58	189.931	467.086	626516.8659	301538.0557
771	58	75.155	538.603	626506.6738	301531.6335
773	63	228.833	543.357	626520.3204	301531.2065
126	64	77.375	89.484	626506.8709	301571.9643
63	71	328.218	38.035	626529.1458	301576.5845
704	77	308.435	478.344	626527.389	301537.0447
455	78	515.077	296.167	626545.7388	301553.4042
750	81	7.043	519.278	626500.6254	301533.3688
131	102	508.784	96.294	626545.18	301571.3528
645	168	302.815	431.726	626526.89	301541.231
732	180	37.061	504.15	626503.291	301534.7273

Appendix 5.0 Photographic Montage

Please note, all photographs shown here have been kindly provided by Dr. Gareth Rees, Senior Lecturer at the Scott Polar Research Institute, Department of Geography, University of Cambridge.

The images were taken during the period November 2014 to January 2015, and from locations near the British Antarctic Survey's Signy Island Research Station situated at Factory Cove, Borge Bay, Signy Island, South Orkney Islands (Latitude 60°43'S, Longitude 45°36'W).

Plate A Two Chinstrap Penguins, *Pygoscelis antarctica*

Plate B Chinstrap Penguins (*Pygoscelis antarctica*) with Sea Ice

Plate C Two Courting Chinstrap (*Pygoscelis antarctica*) Penguins

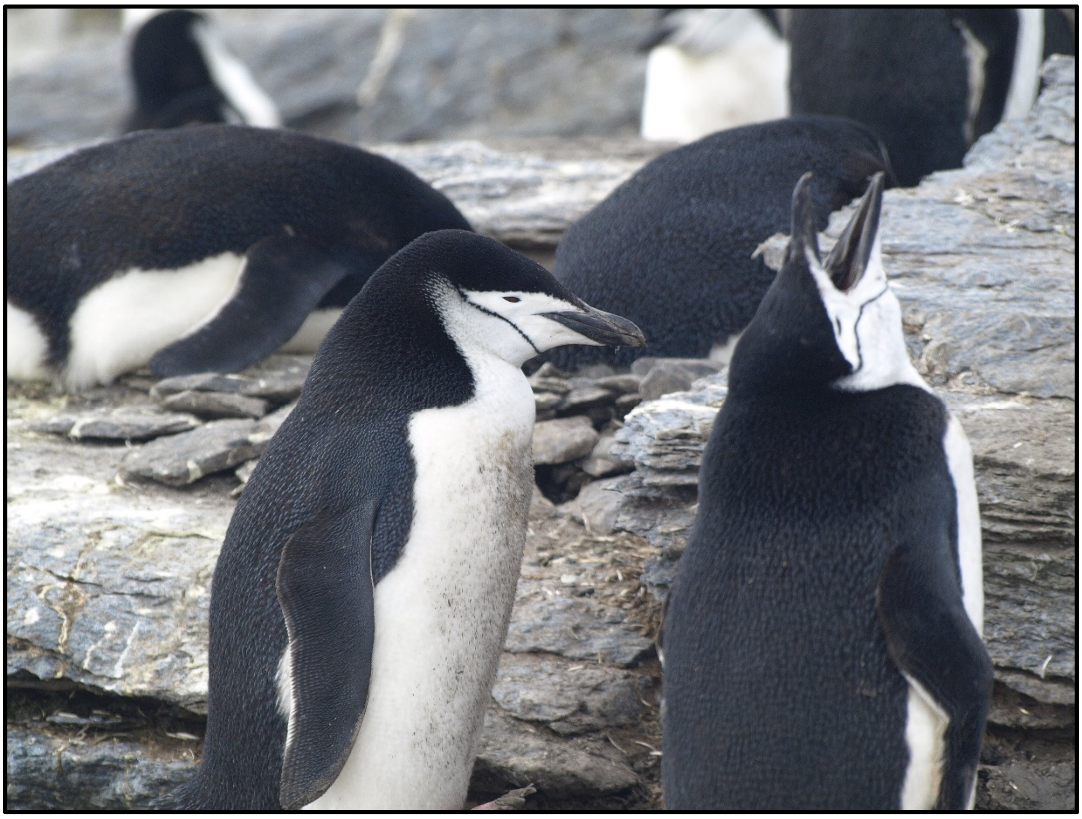


Plate D One Giant Leap for Penguin-kind…

Plate E Adult Chinstrap (*Pygoscelis antarctica*) Penguin & Chicks

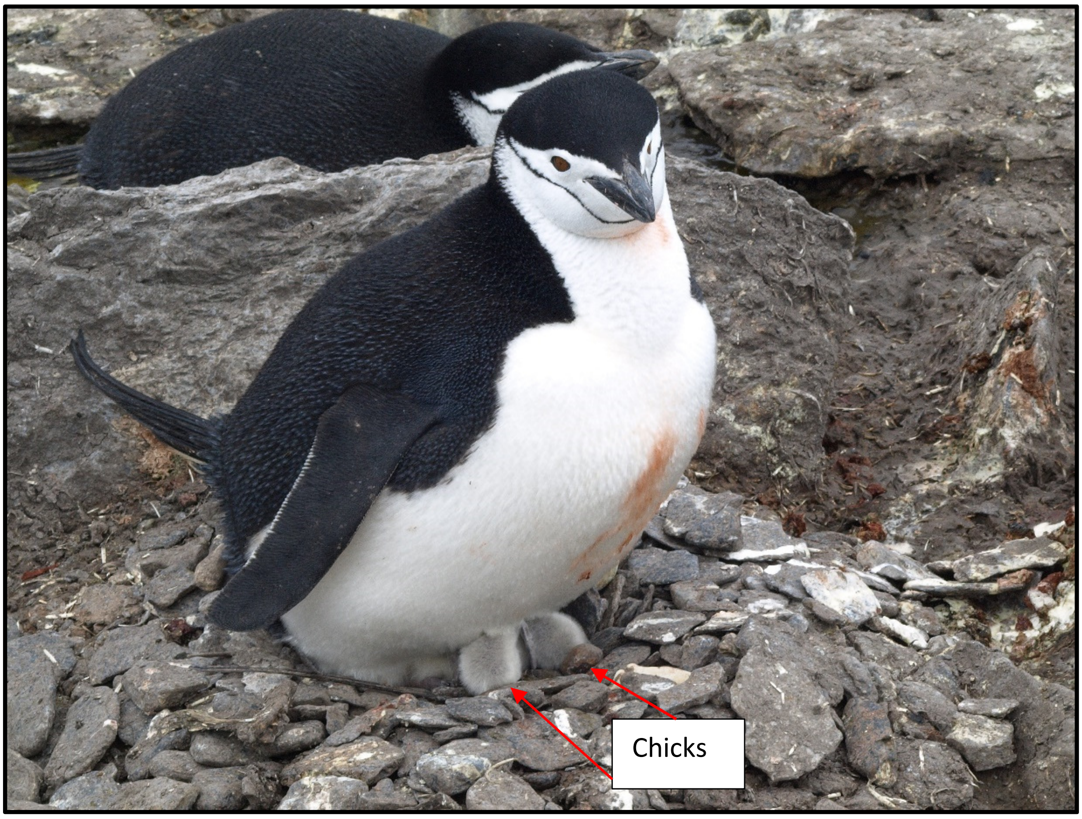


Plate F Gentoo (*Pygoscelis papua*) Penguin on Ice

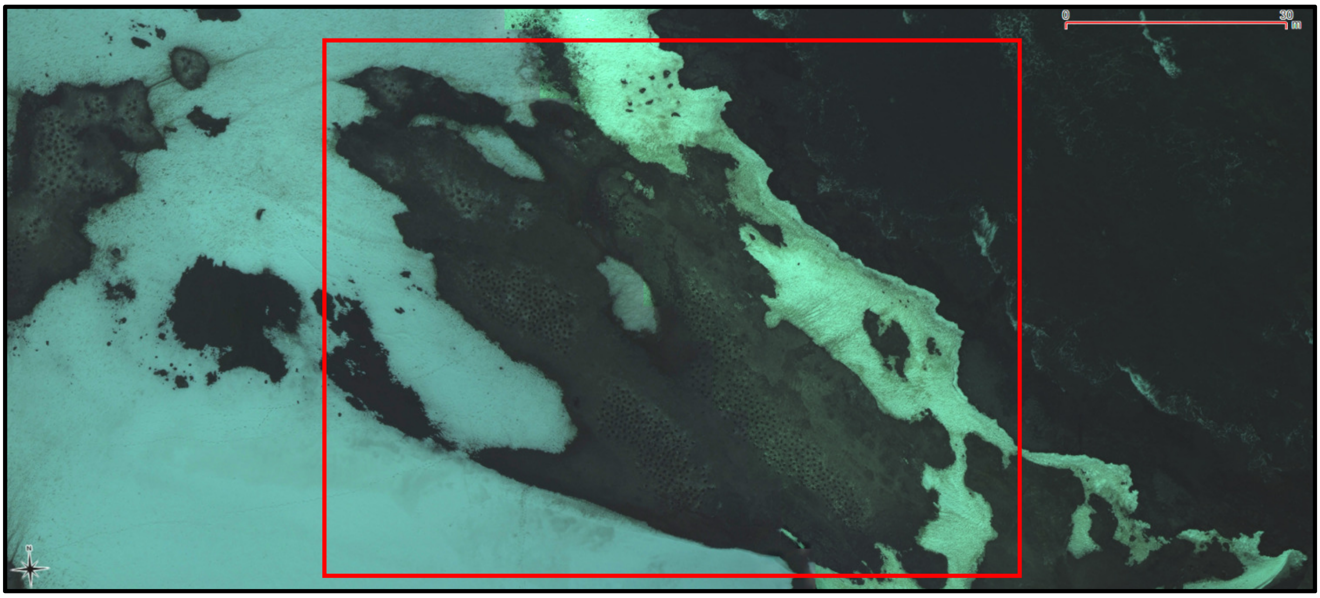
Plate G Gentoo (*Pygoscelis papua*) Penguin Displaying

Plate H Gentoo (*Pygoscelis papua*) Penguin Sub-Colony

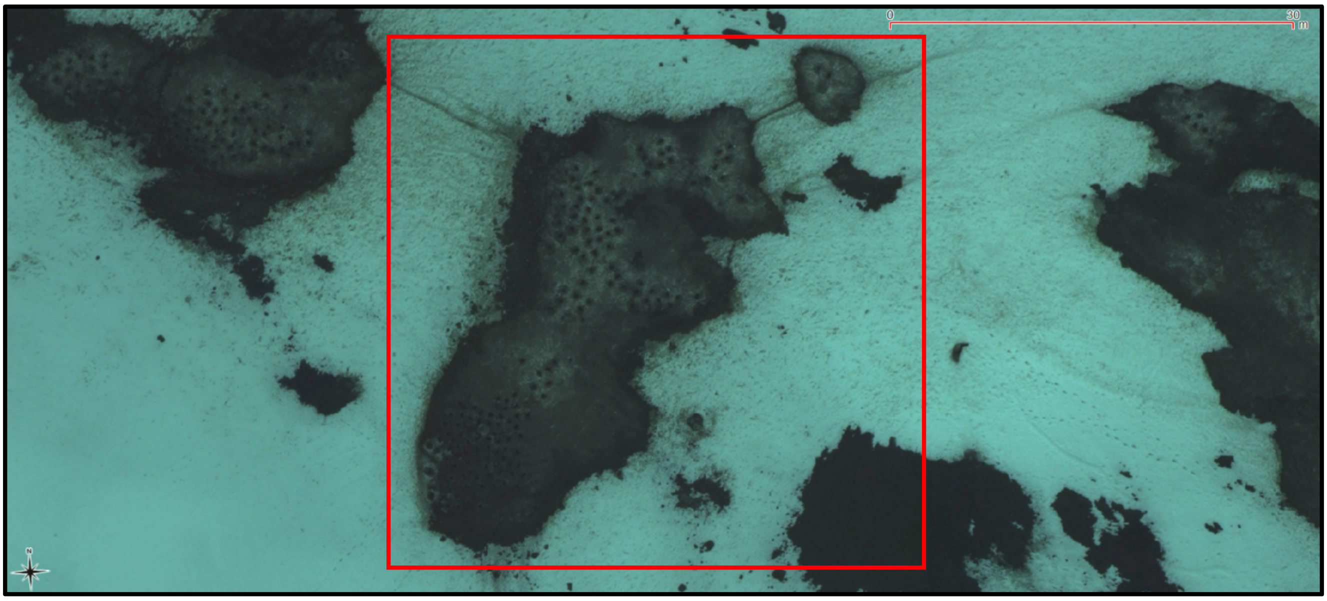
Plate I Gentoo (*Pygoscelis papua*) Penguin with Chicks

Appendix 6.0 Isolated Colony Image Extracts: With/out Respective Manual Counts

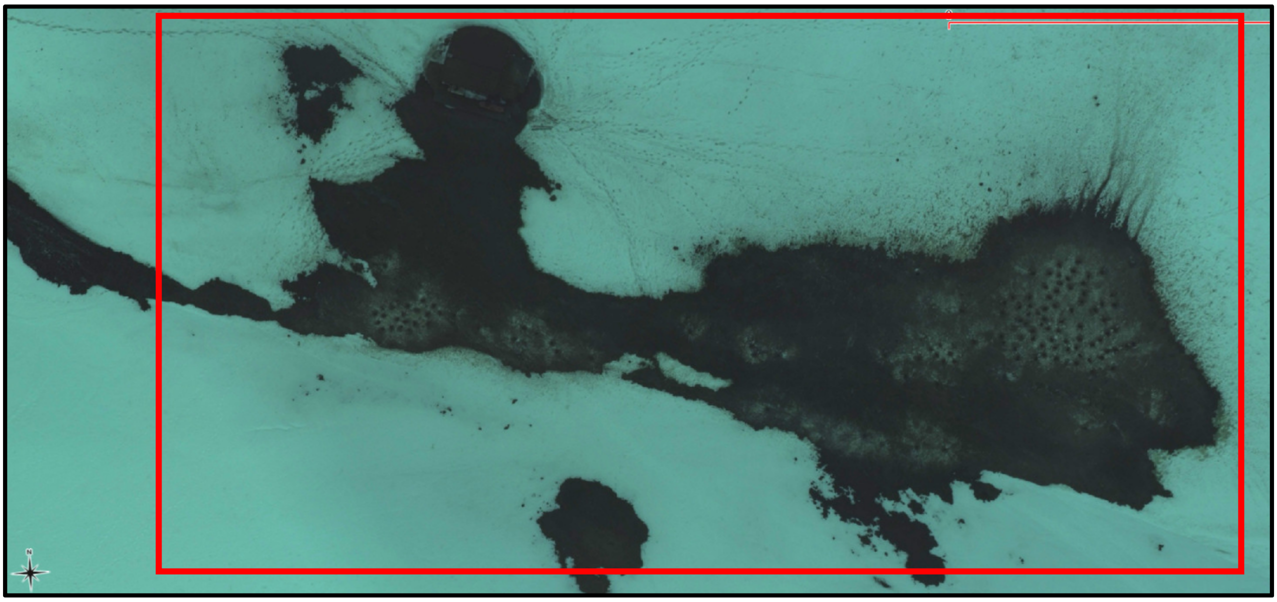
Colony 3



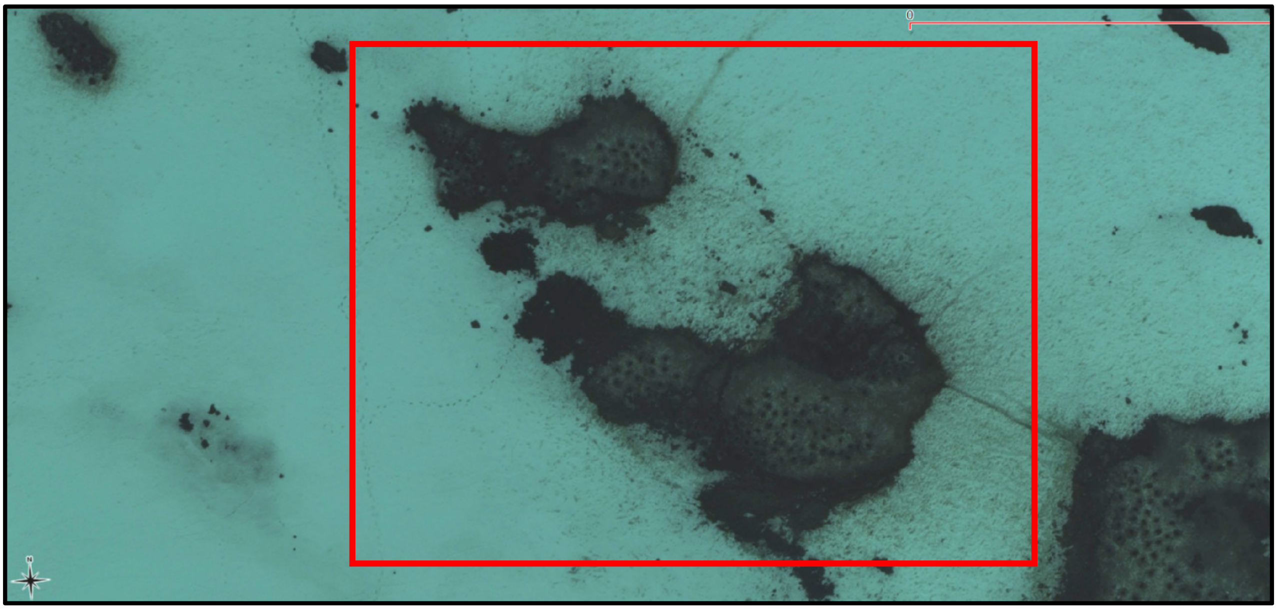
Colony 5



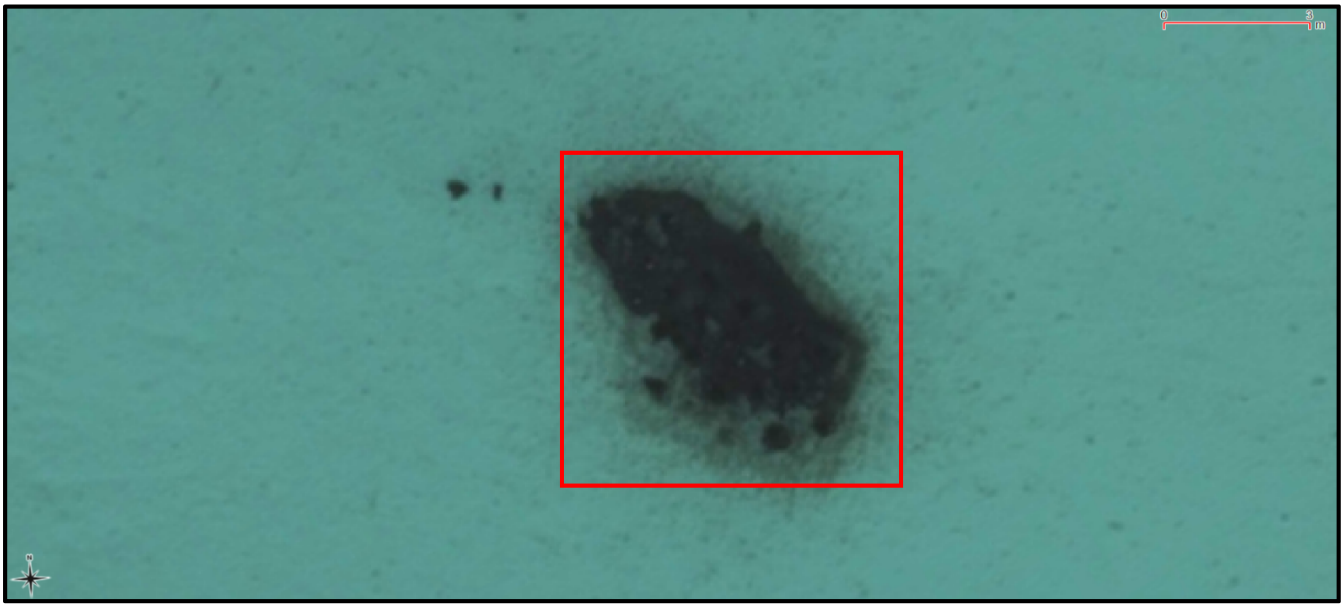
Colony 6



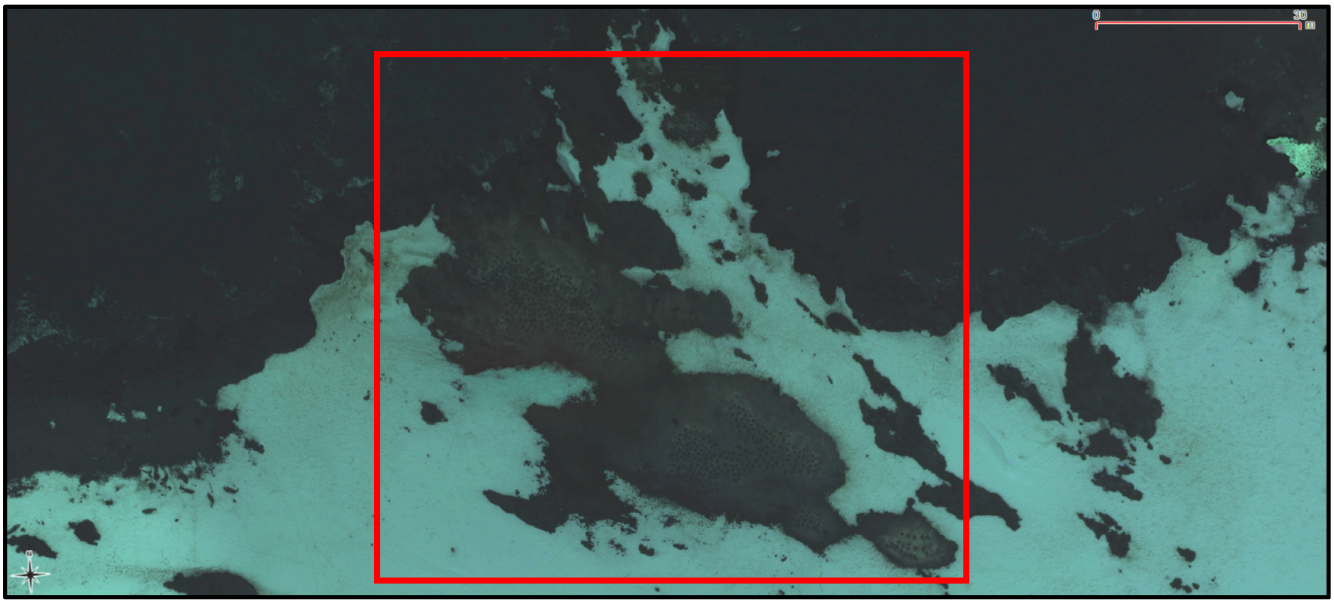
Colony 8



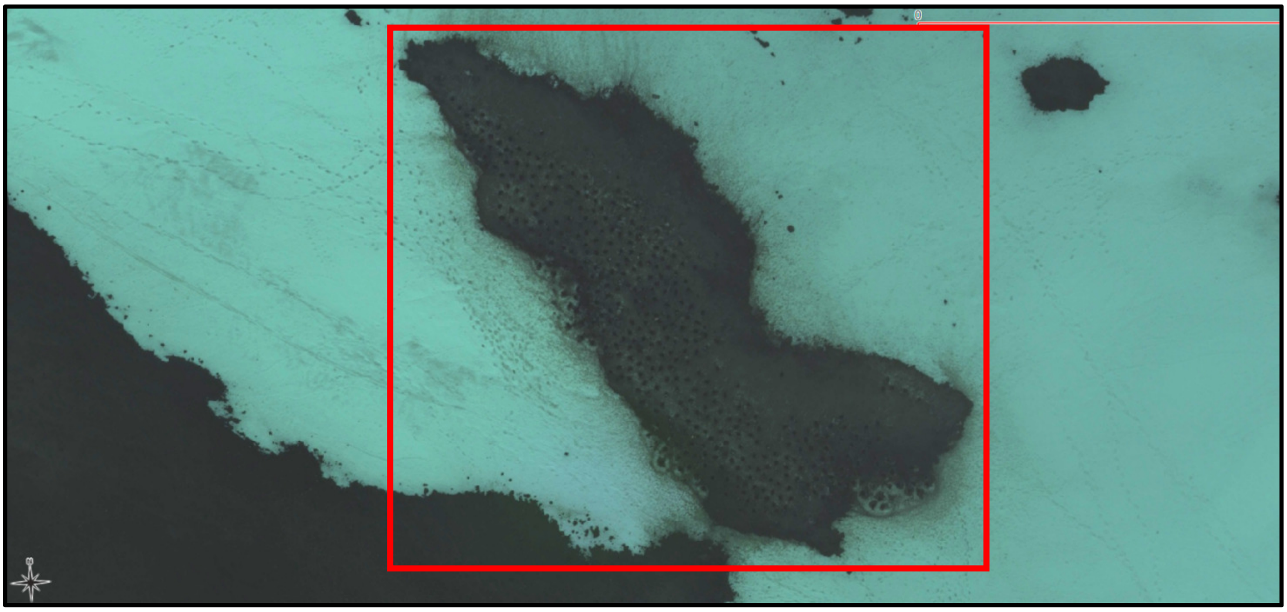
Colony 9



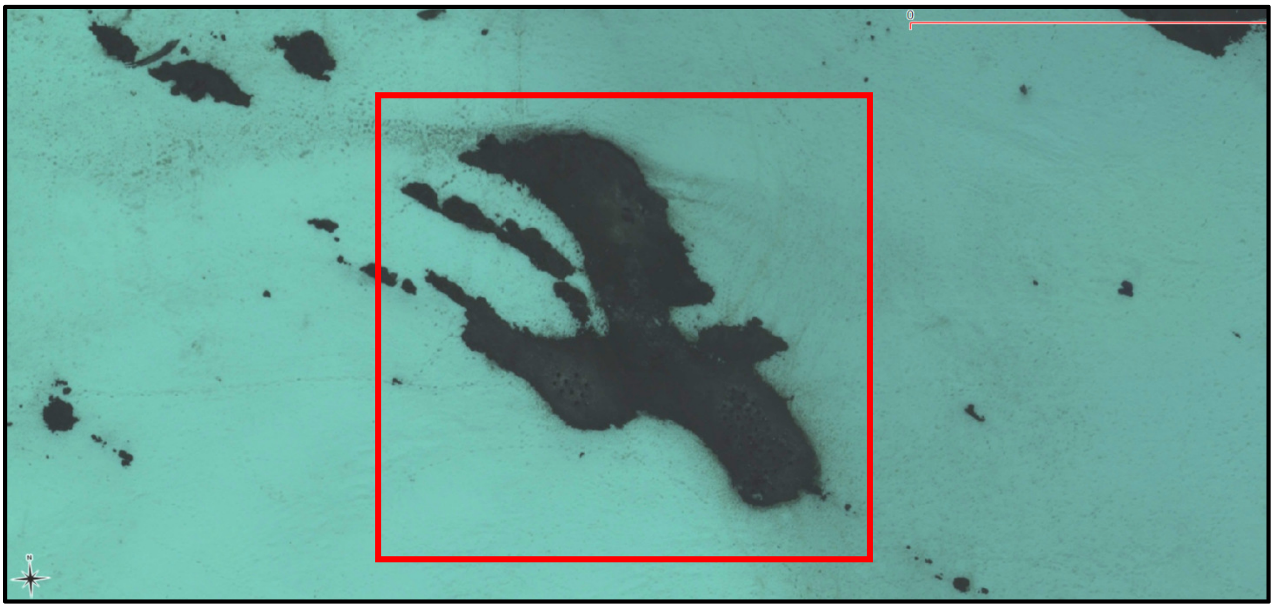
Colony 10



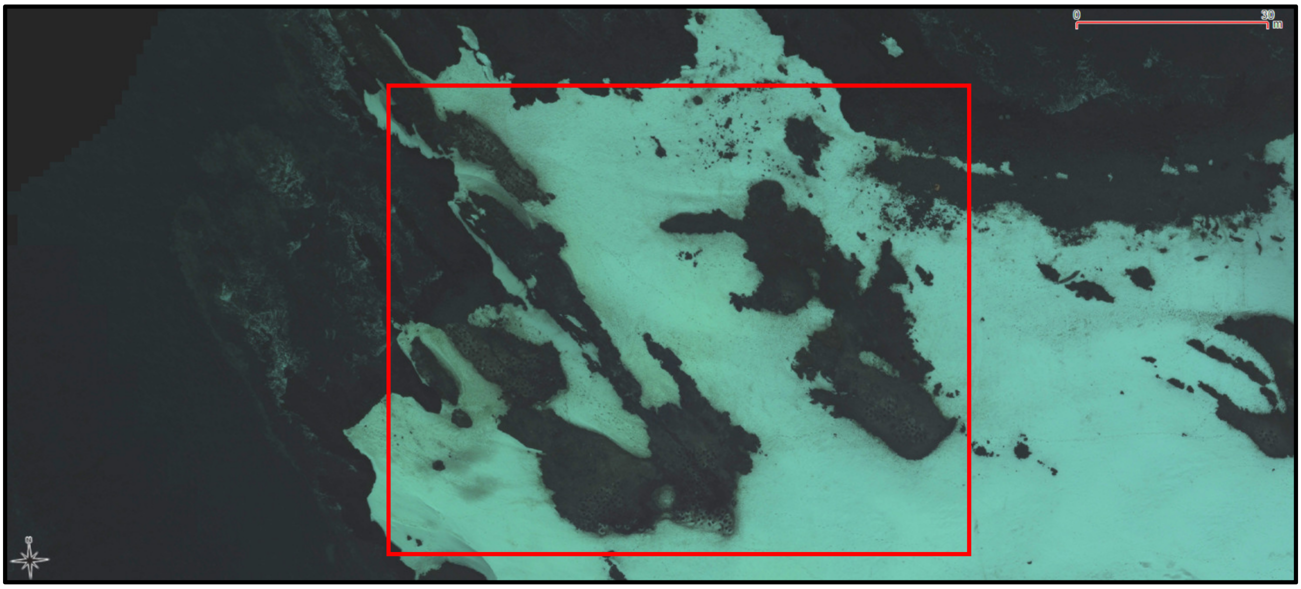
Colony 11



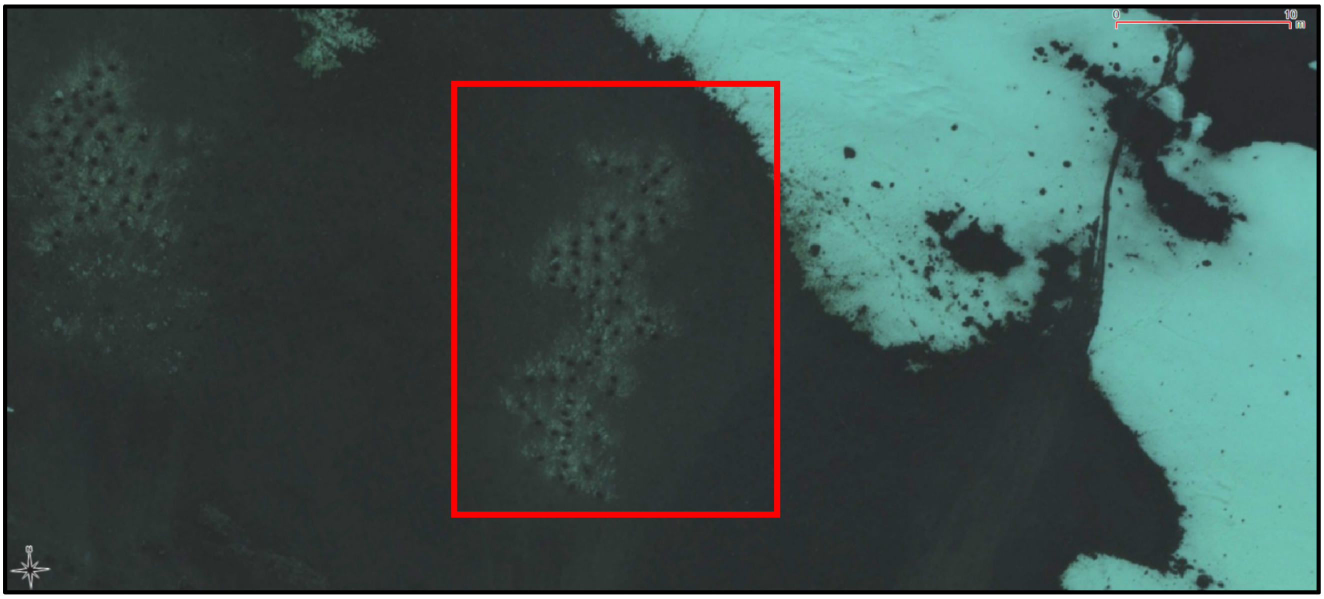
Colony 12



Colonies 13 & 14

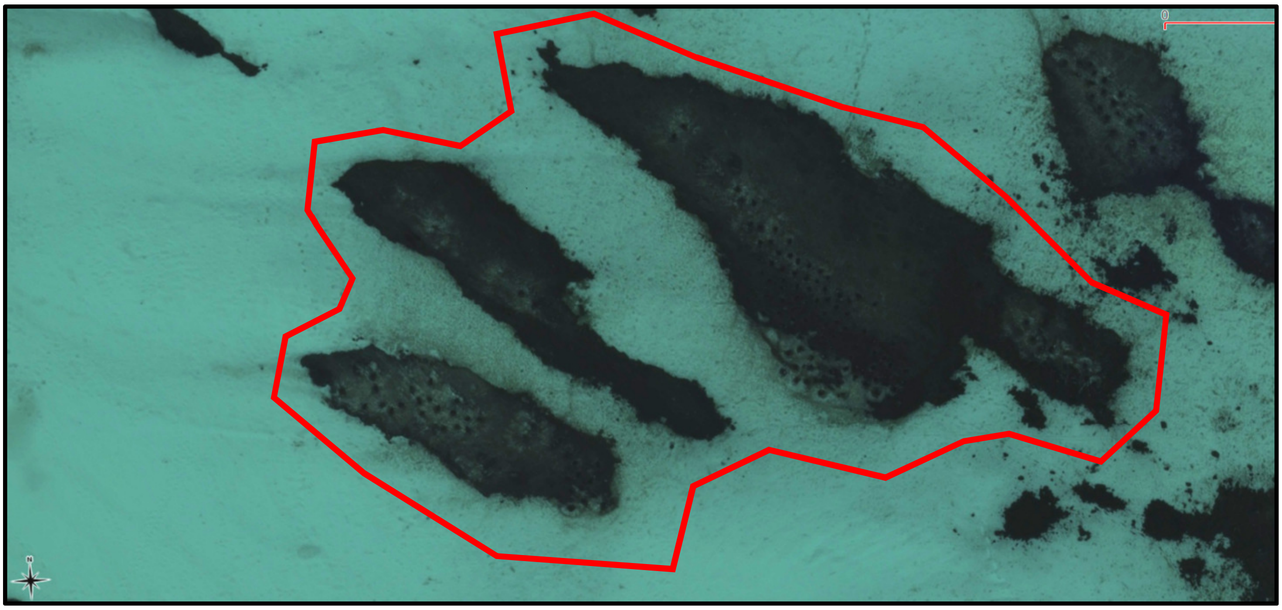


Colony 17

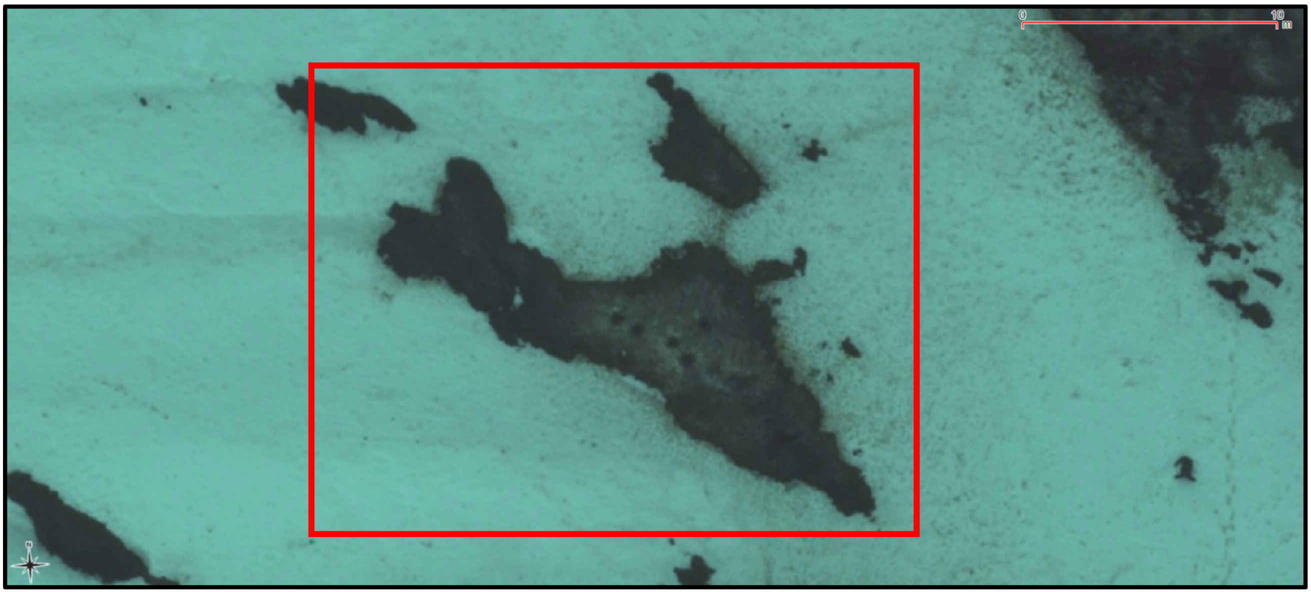


Colony 18

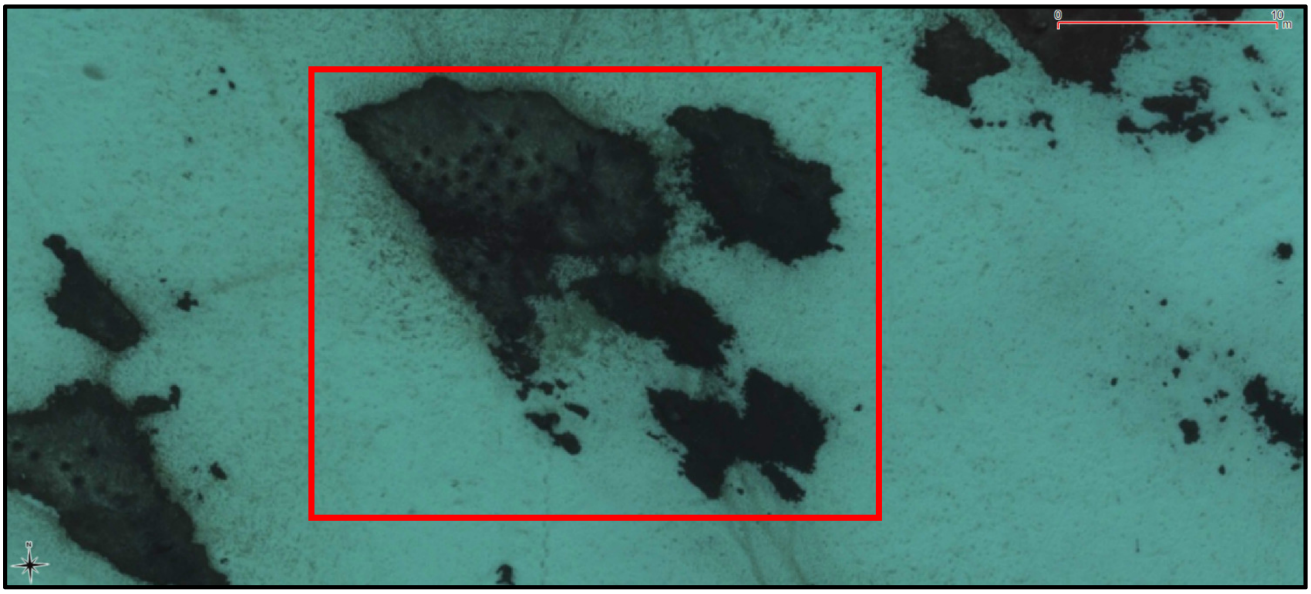
Colony 20



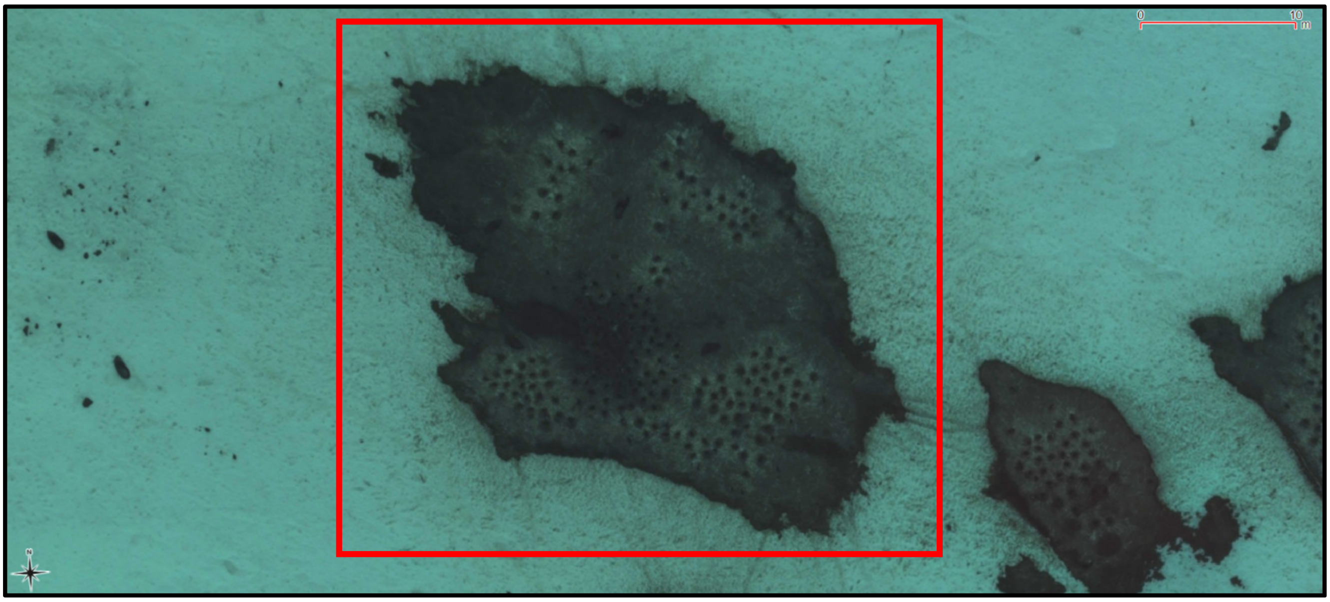
Colony 21



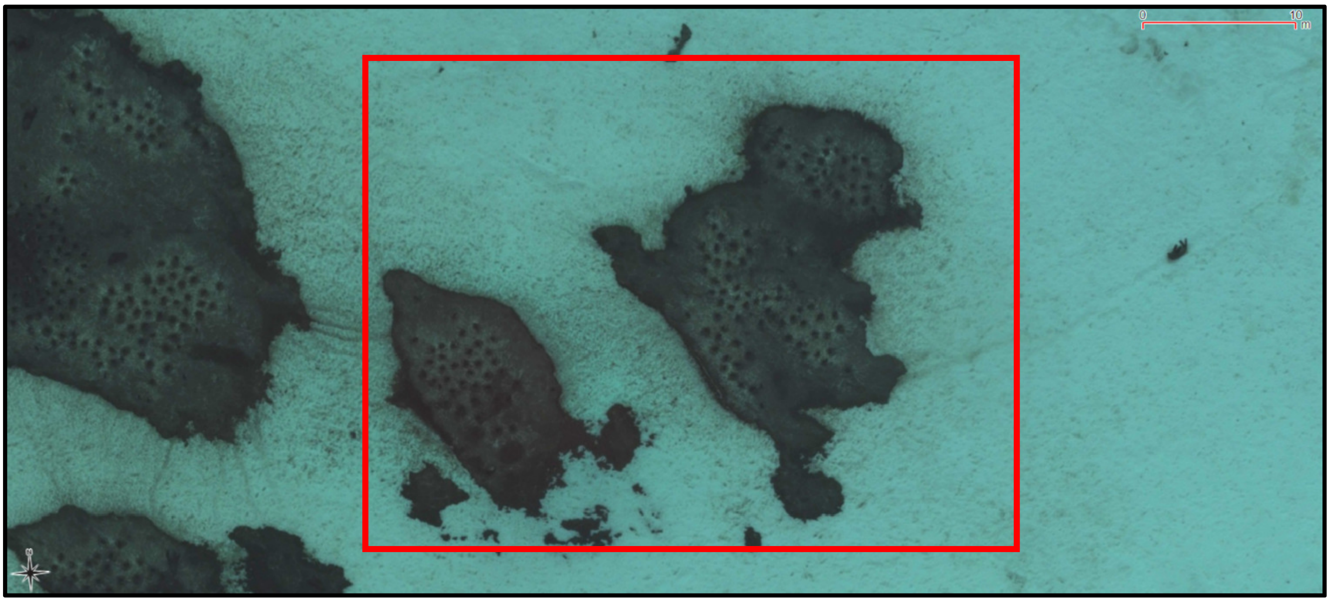
Colony 22



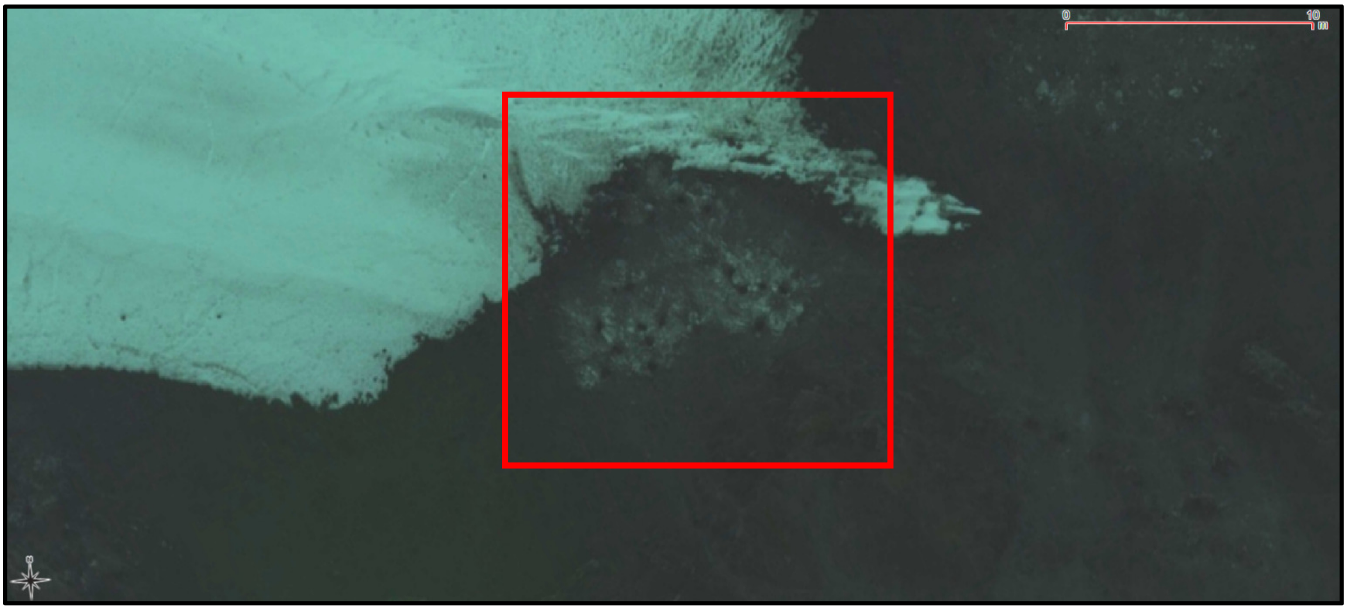
Colony 23



Colony 24

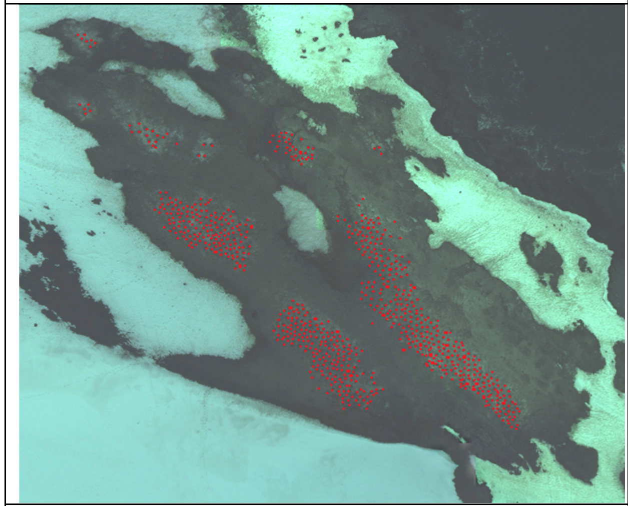
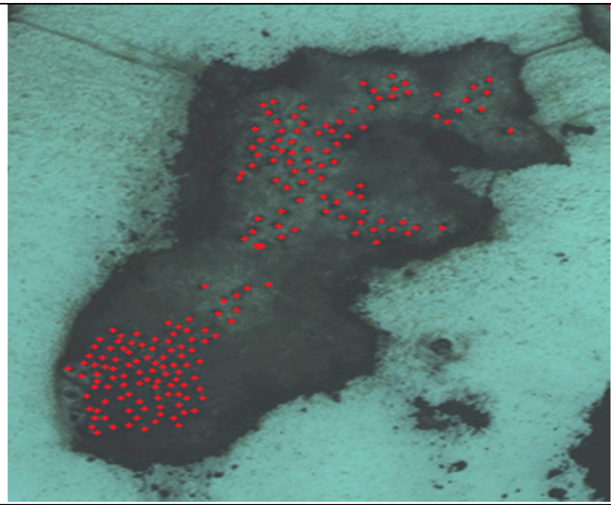
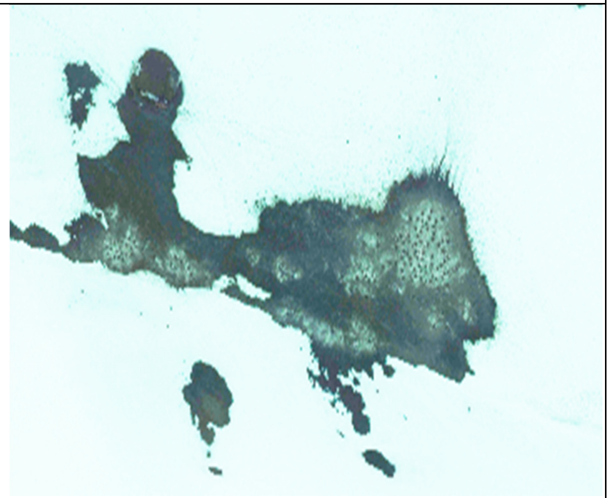
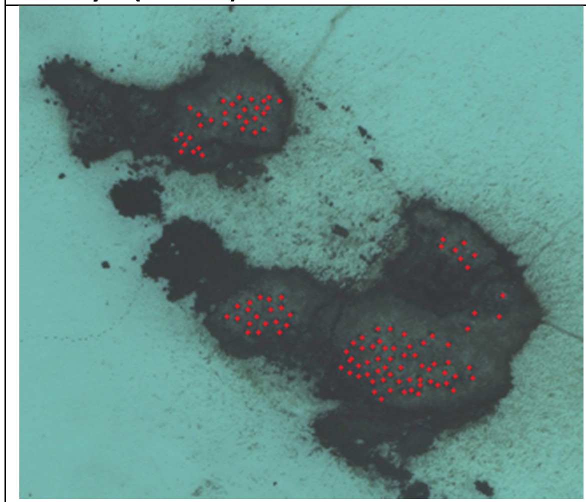
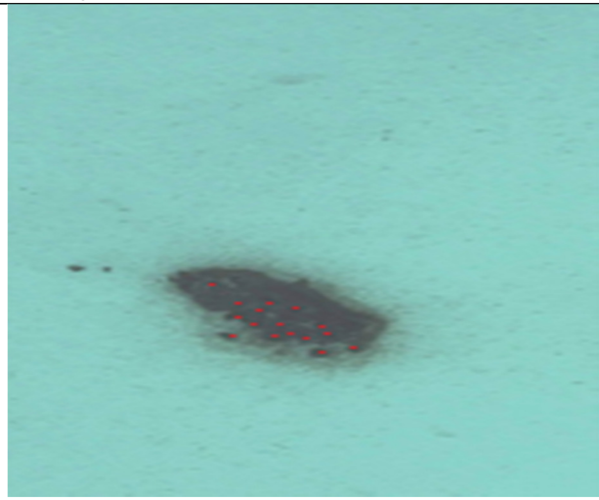
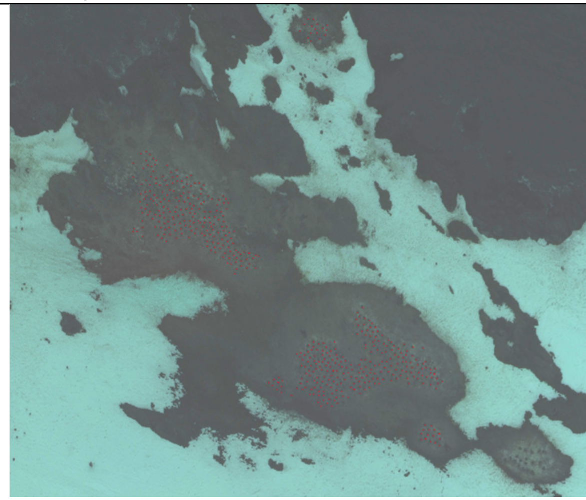


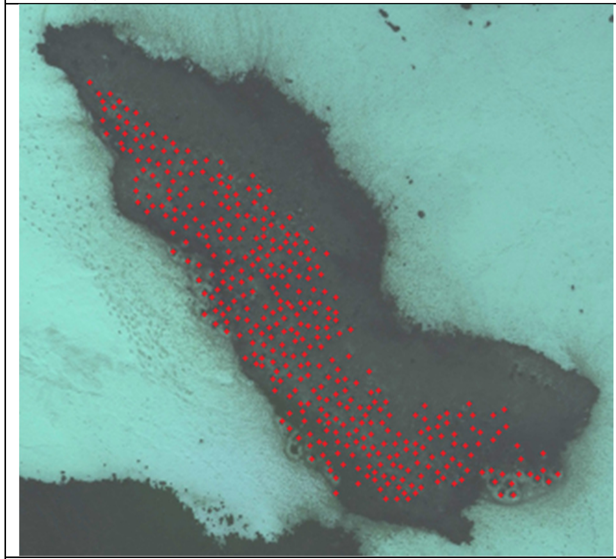
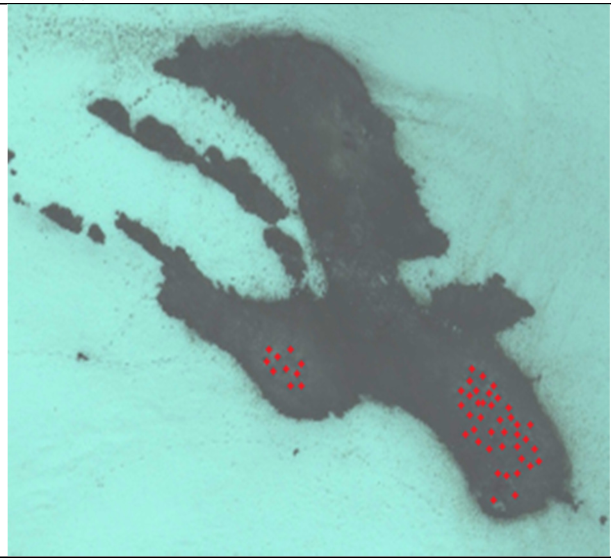
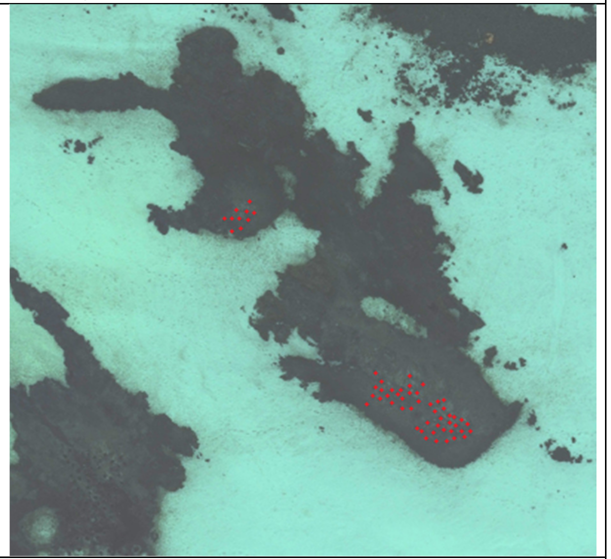
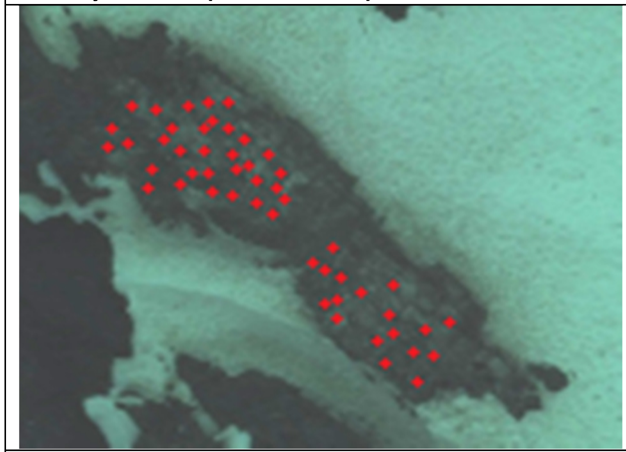
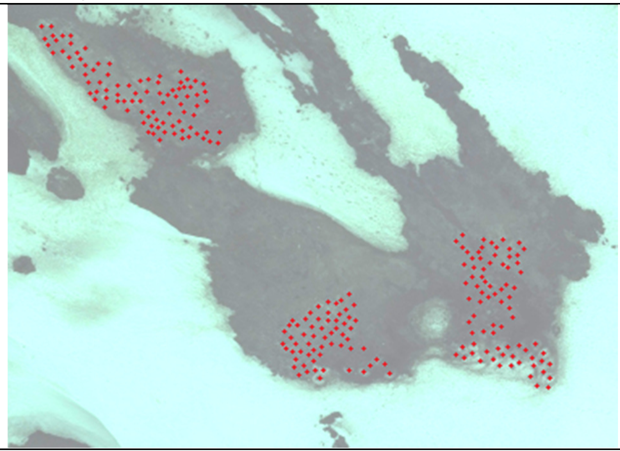
Colony 27



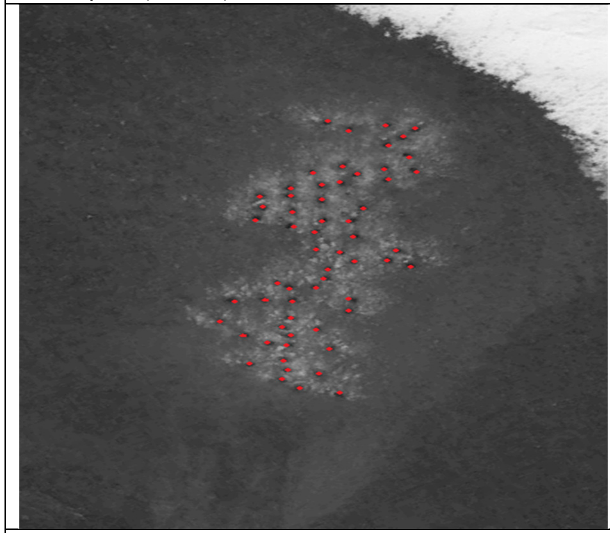
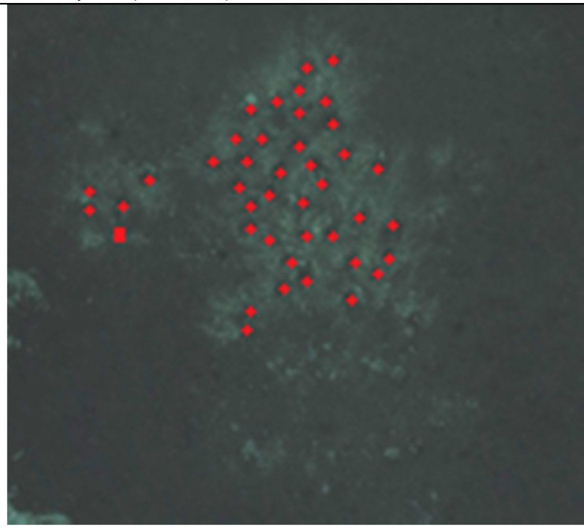
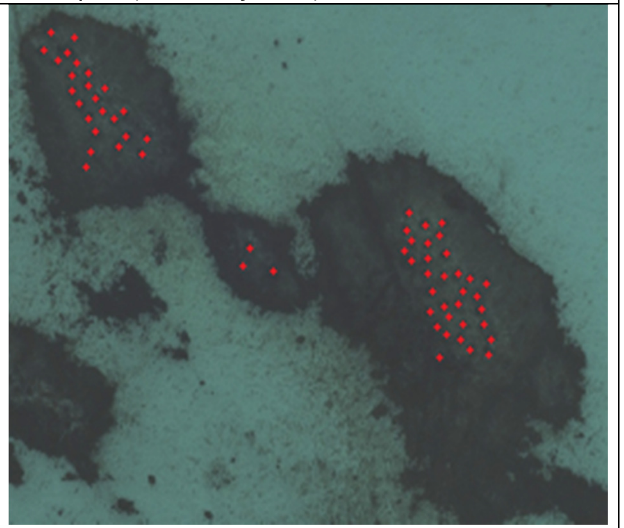
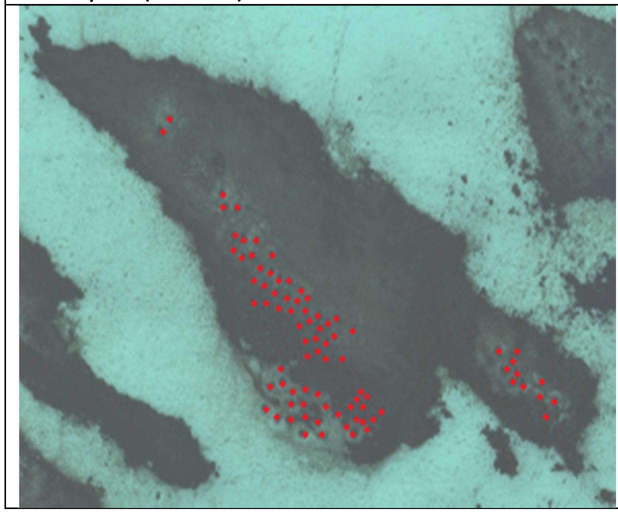
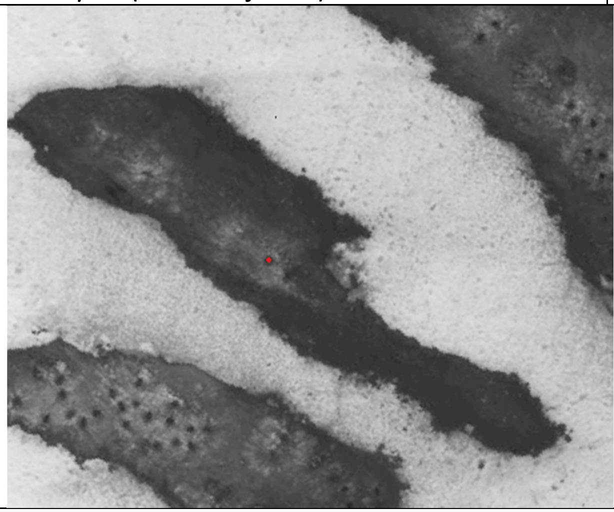
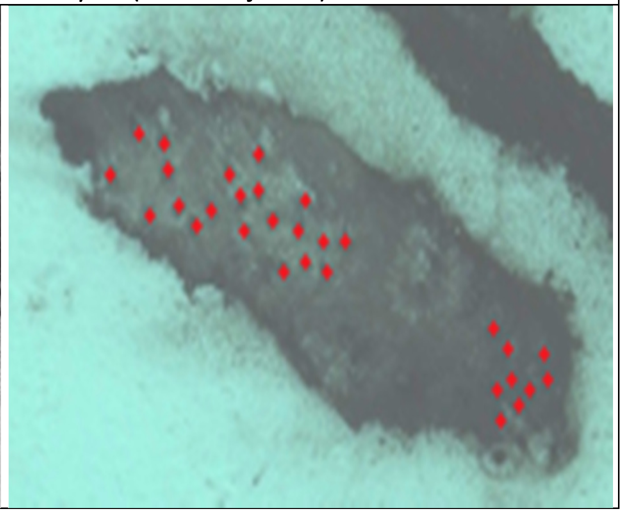
Colony 29

Region 1: Post-Manual Counting

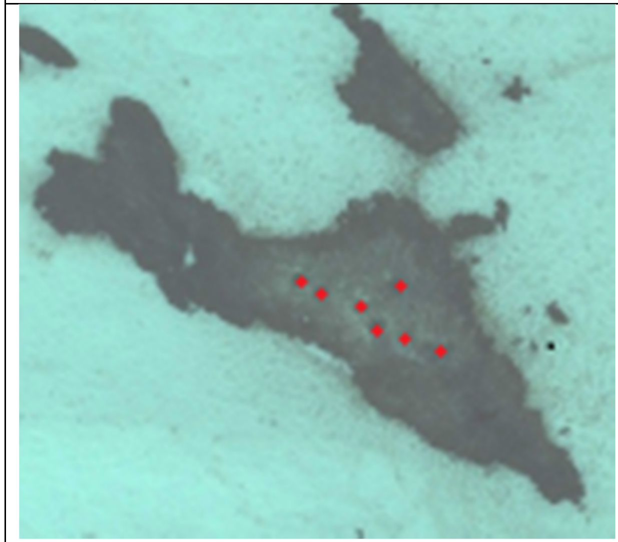
Region 1 (Eastern)		
Colony 3 (n = 705)	**Colony 5 (n = 185)**	**Colony 6 (n = 116)**
		
Colony 8 (n = 114)	**Colony 9 (n = 16)**	**Colony 10 (n = 478)**
		

Colony 11 (n = 402)	**Colony 12 (n = 53)**	**Colony 13 + 14 (n = 334)**
		
Colony 13 + 14 (n = as above)	**Colony 13 + 14 (n = as above)**	
		

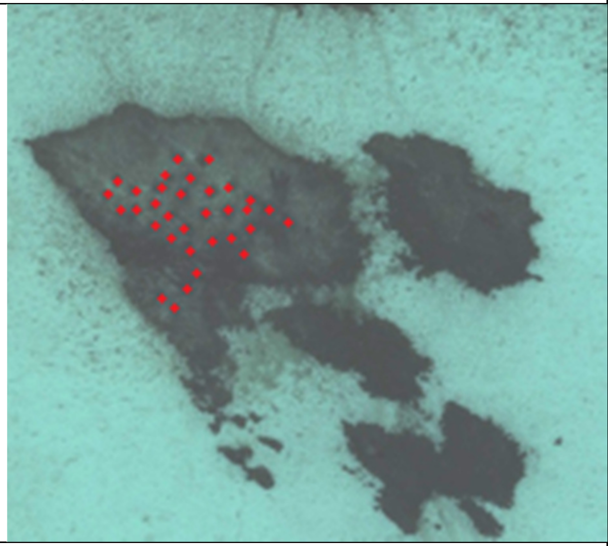
Region 2: Post-Manual Counting

Region 2 (Western)		
Colony 17 (n = 60)	Colony 18 (n = 102)	Colony 18 (n = as adjacent)
		
Colony 20 (n = 113)	Colony 20 (n = as adjacent)	Colony 20 (n = as adjacent)
		

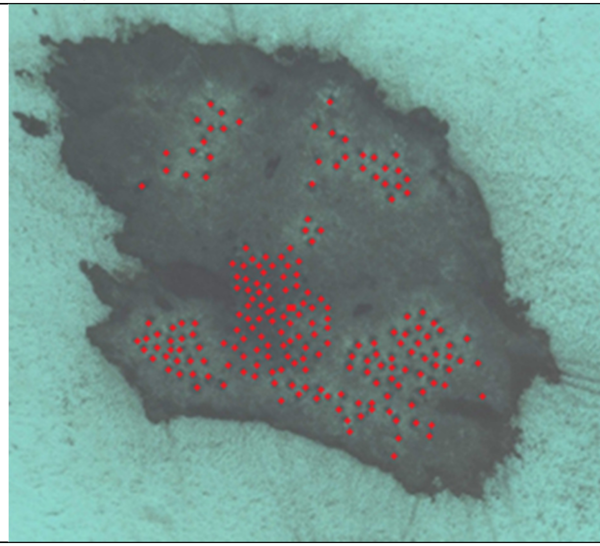
Colony 21 (n = 7)



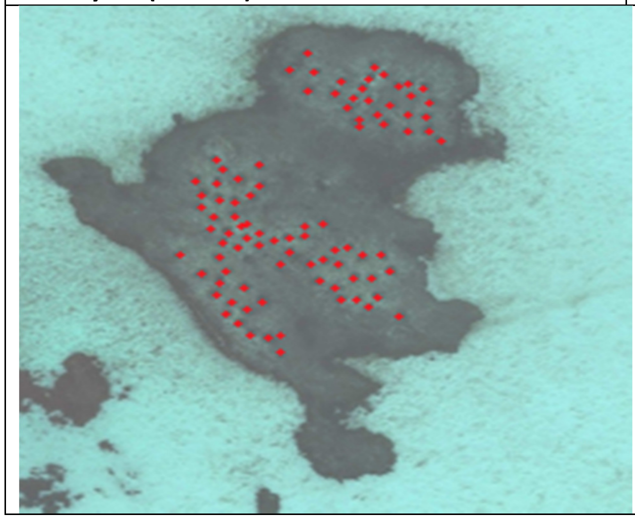
Colony 22 (n = 32)



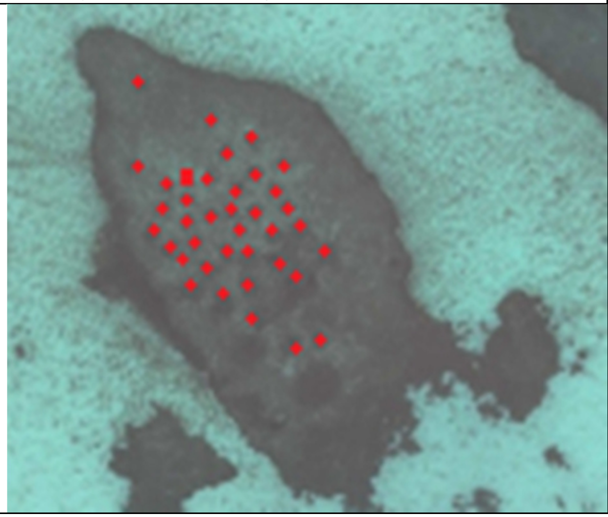
Colony 23 (n = 199)



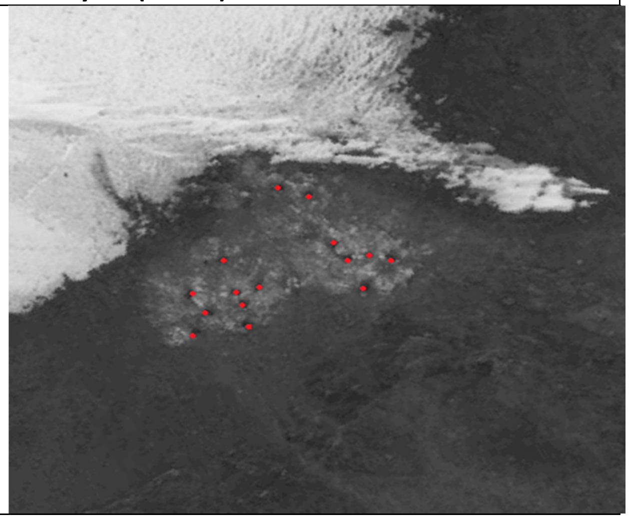
Colony 24 (n = 126)



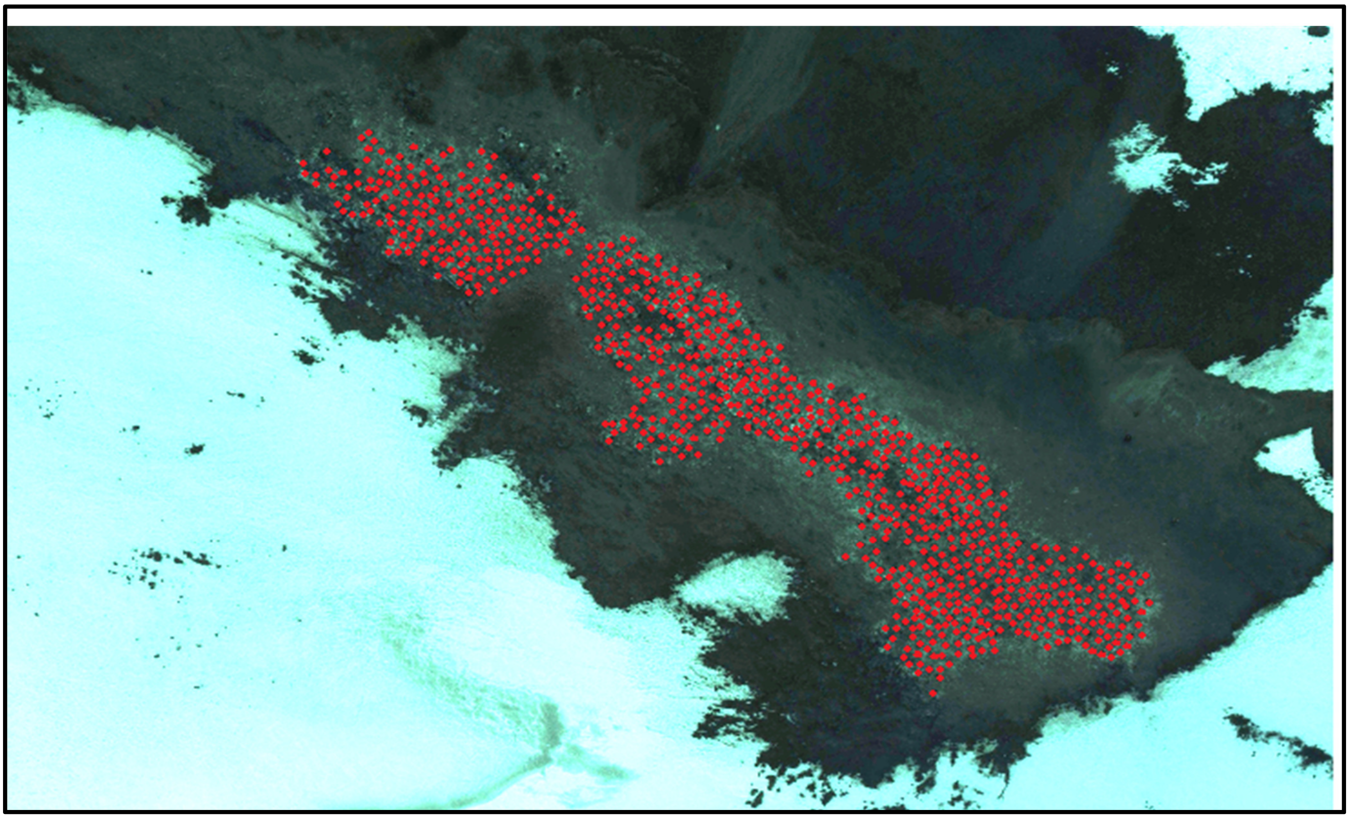
Colony 24 (n = see adjacent)



Colony 27 (n = 15)



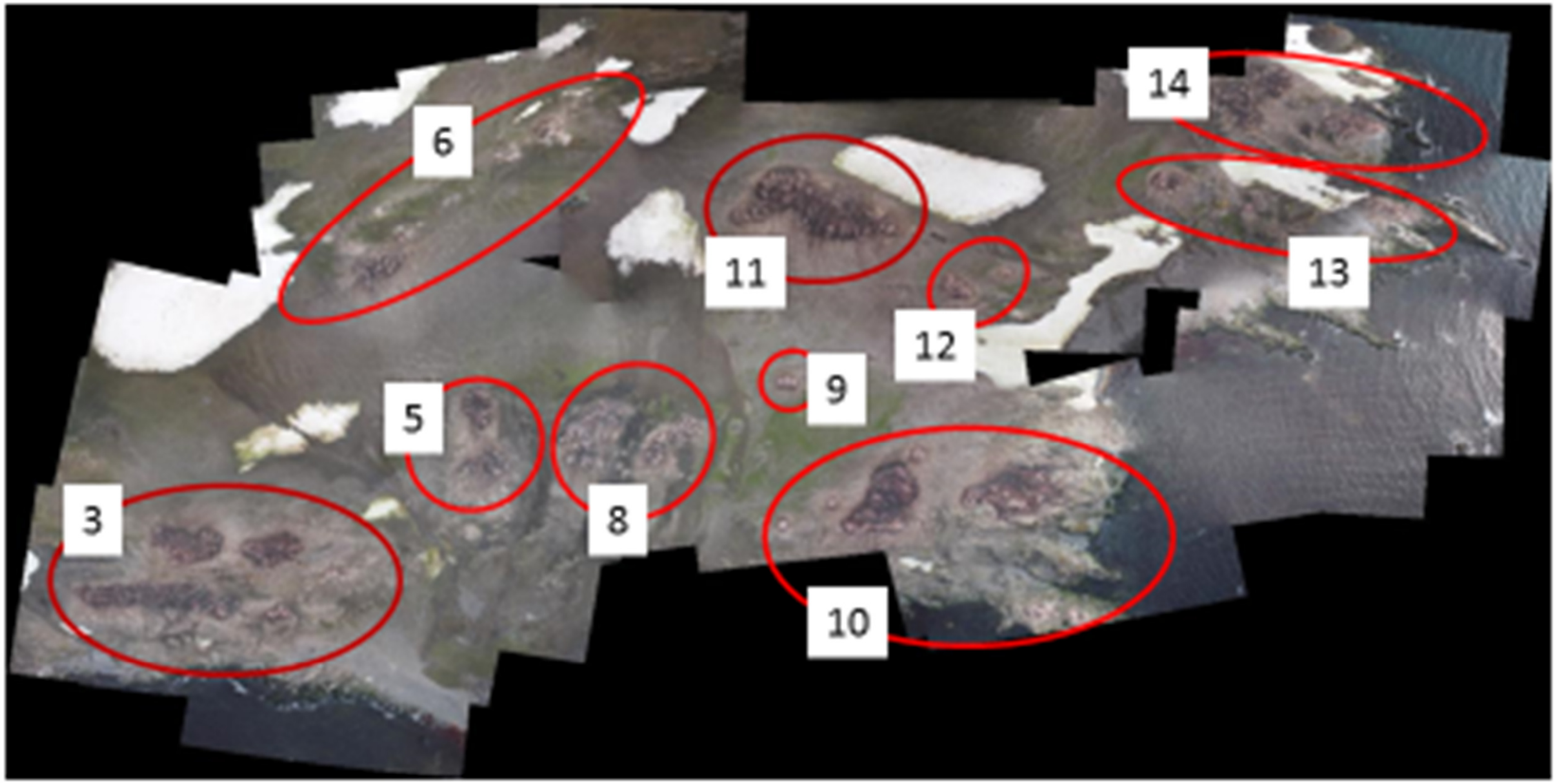
Colony 29 (the Largest Colony by Population)



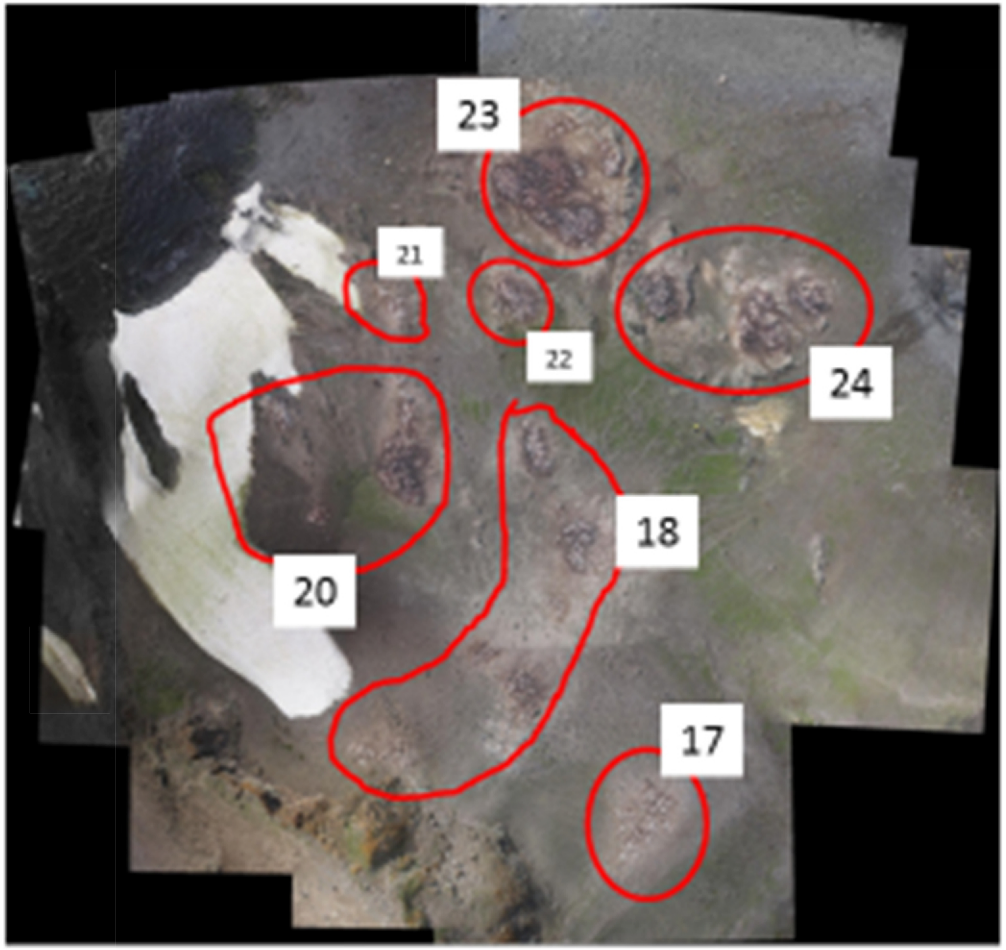
Appendix 7.0 US AMLR 2013-14 Season Data (Unpublished)

YEAR	PROJECT	SPECIES	ROOKERY	COLONY	DATE NN	NN	DATE NCK	NCK
2013-14	CS	3	0	3	41609	709	41683	690
2013-14	CS	3	0	5	41609	81	41683	73
2013-14	CS	3	0	2	41609	291	41683	259
2013-14	CS	3	0	9	41609	30	41683	21
2013-14	CS	3	0	10	41609	464	41683	457
2013-14	CS	3	0	11	41610	399	41683	402
2013-14	CS	3	0	14	41610	267	41683	230
2013-14	CS	3	0	23	41610	65	41683	62
2013-14	CS	3	0	20	41610	91	41683	67
2013-14	CS	3	0	13	41610	107	41683	91
2013-14	CS	3	0	12	41610	53	41683	45
2013-14	CS	3	0	8	41610	74	41683	66
2013-14	CS	3	0	27	41610	13	41683	6
2013-14	CS	3	0	29	41612	938	41683	1029
2013-14	CS	2	0	17	41607	56	NA	NA
2013-14	CS	2	0	18	41607	135	NA	NA
2013-14	CS	2	0	20	41607	34	NA	NA
2013-14	CS	2	0	21	41607	7	NA	NA
2013-14	CS	2	0	22	41607	33	NA	NA
2013-14	CS	2	0	23	41607	120	NA	NA
2013-14	CS	2	0	24	41607	99	NA	NA
2013-14	CS	2	0	10	41607	18	NA	NA
2013-14	CS	2	0	8	41607	94	NA	NA
2013-14	CS	2	0	5	41607	82	NA	NA
2013-14	CS	2	0	3	41607	31	NA	NA
2013-14	CS	2	0	6	41607	130	NA	NA
2013-14	CS	2	0	WEST	NA	NA	41672	518
2013-14	CS	2	0	EAST	NA	NA	41672	349

East colonies: 3, 5, 6, 8, 9, 10, 11, 12, 13, 14.



West Colonies: 17, 18, 20, 21, 22, 23, 24



West Colonies: 27, 29

Note: 27 Had failed by census time, so no photo
Taken in 2012/13.

29 is on hilltop above all other west colonies

Non-disturbance colonies: 2

Appendix 8.0 Compilation of ImageJ Tables & Outputs for the Semi-Automated Counting Approach

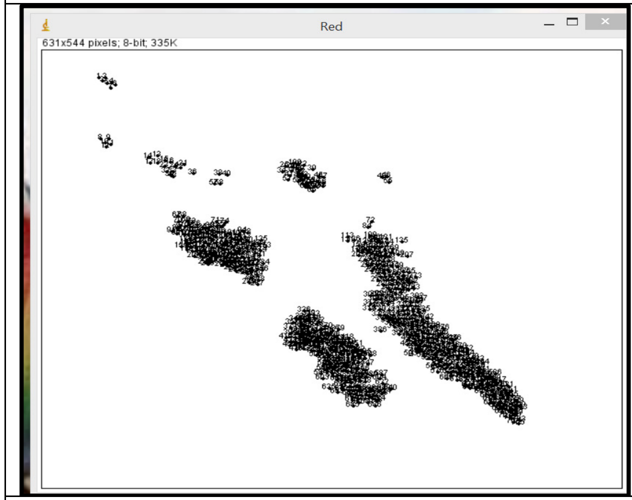
Figure 8-a provides screen-shots of the results from the semi-automated processing of the colony images within ImageJ.

Tables 8-a and 8-b provide analysis of both the accuracy and the time taken for the manual counting and semi-automated counting approaches when calculated for colonies of less than 250 nests, and for colonies of 250 or more nests, respectively.

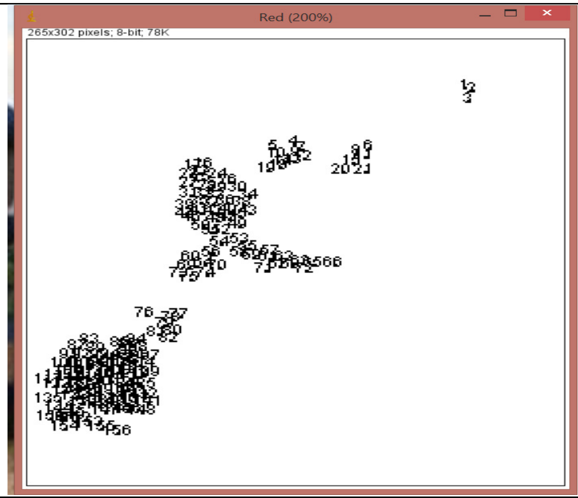
Figure 8a Compilation of Image J Outputs for the Semi-Automated Counting of the *Pygoscelid* Colonies at Cape Shirreff

Region 1 (Eastern)

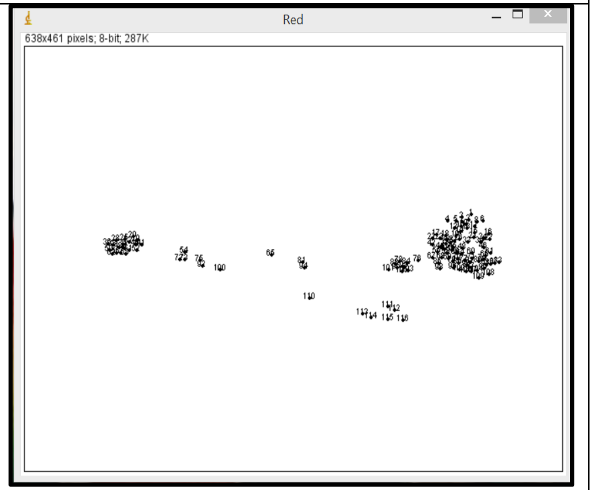
Colony 3 (n = 705)



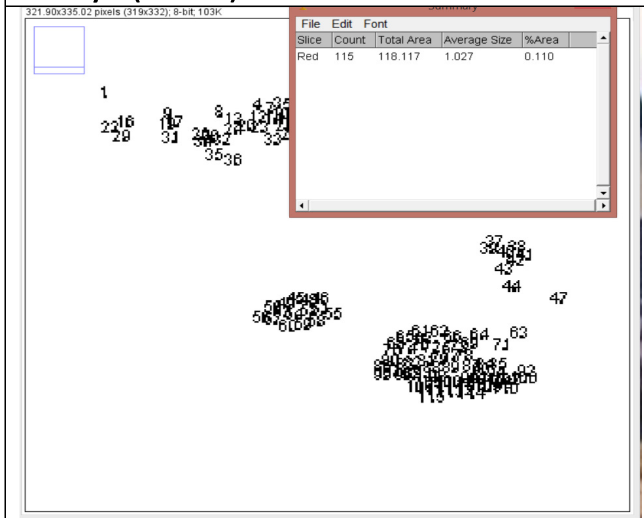
Colony 5 (n = 156)



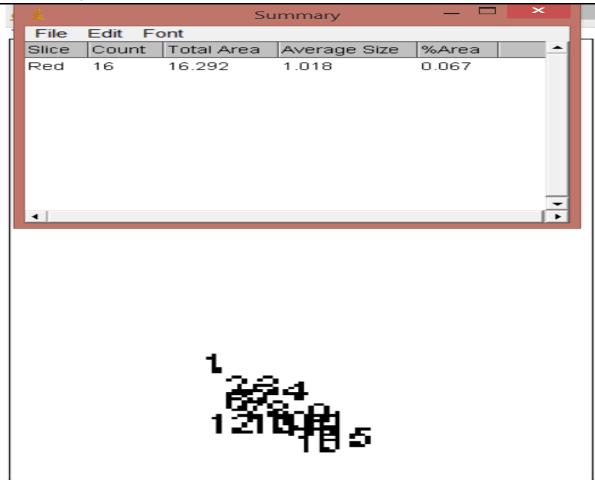
Colony 6 (n = 116)



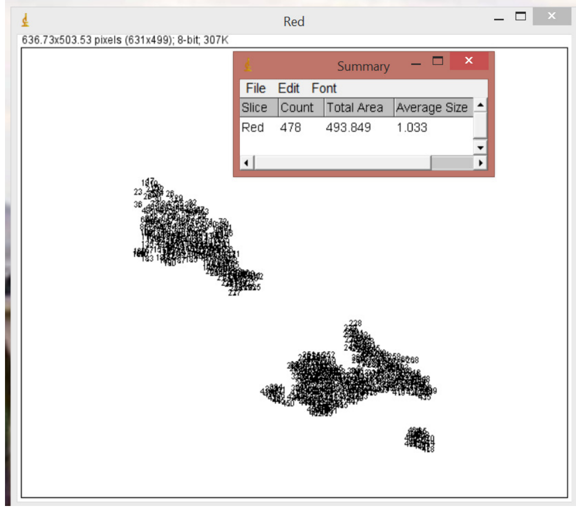
Colony 8 (n = 115)

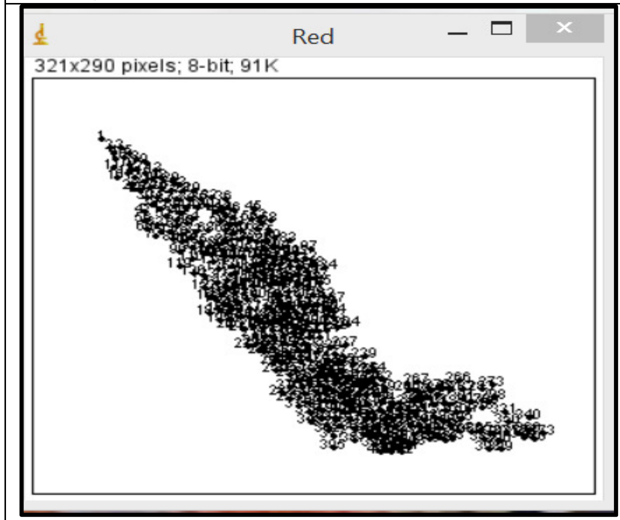
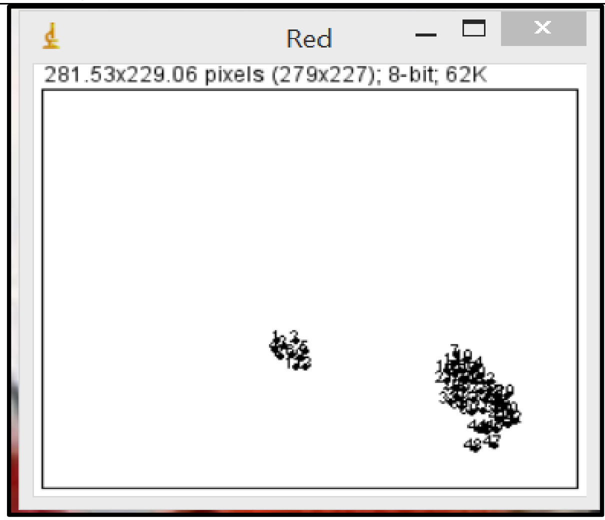
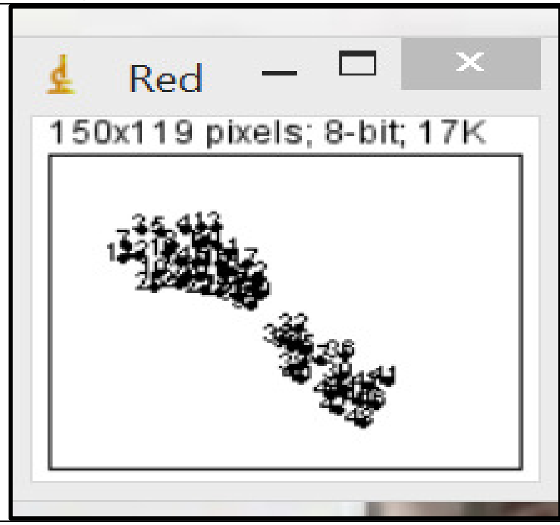
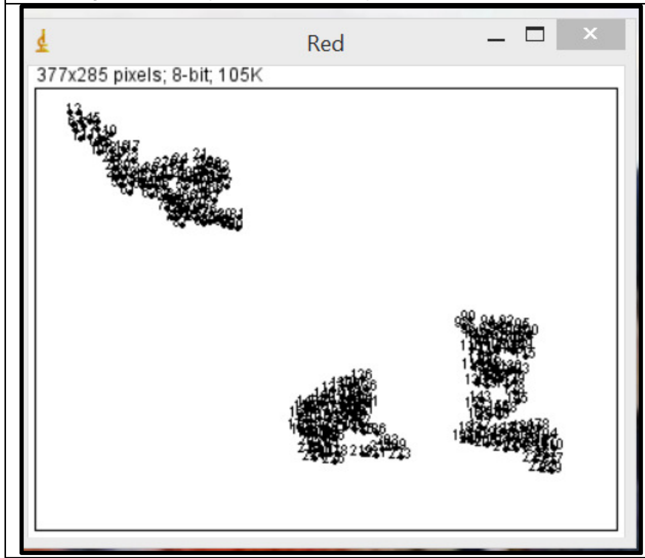
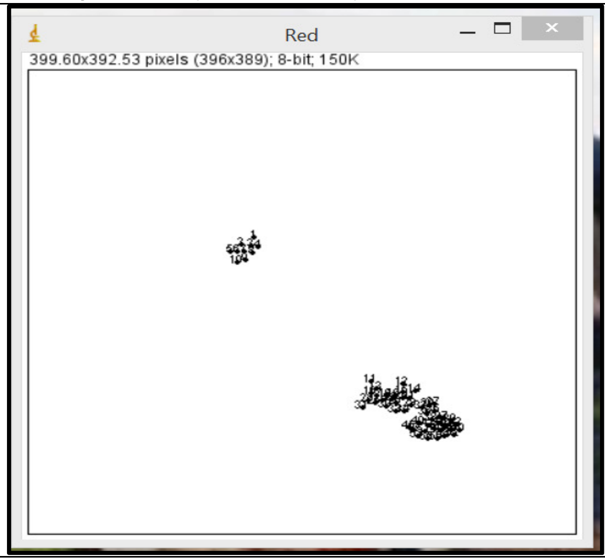


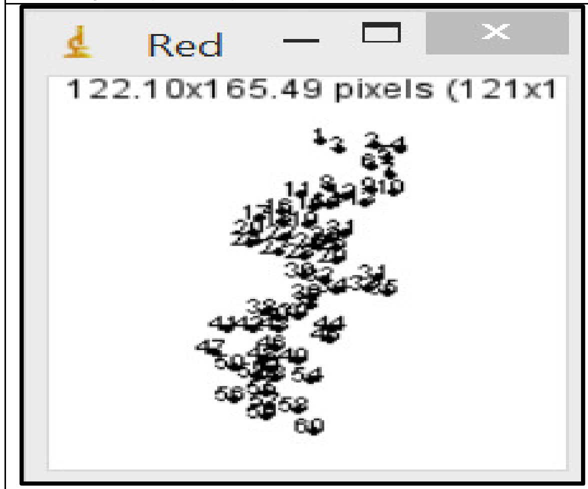
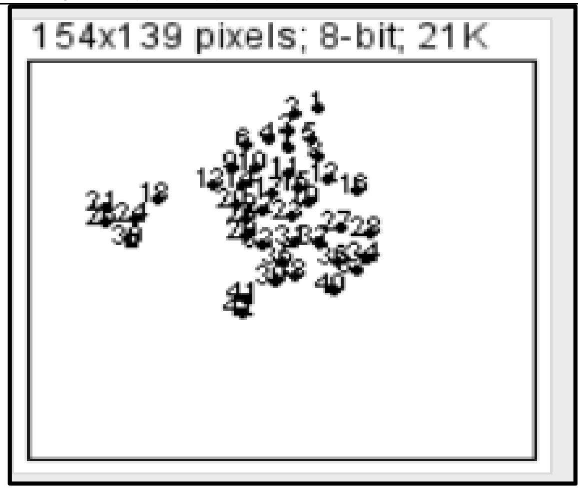
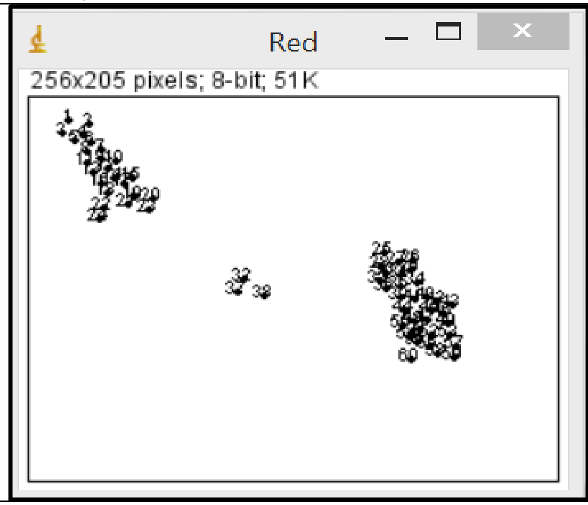
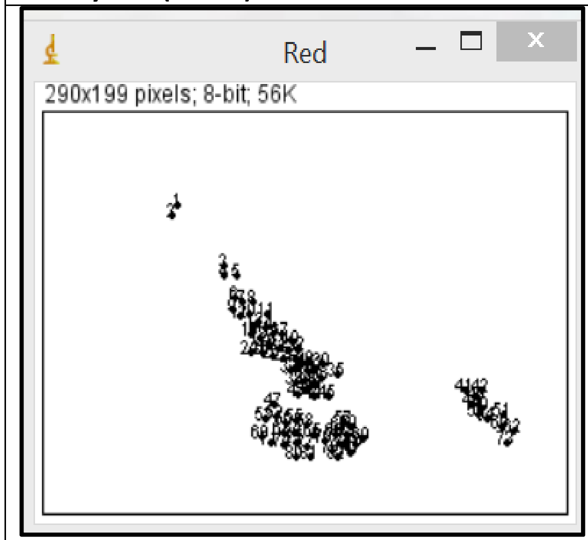
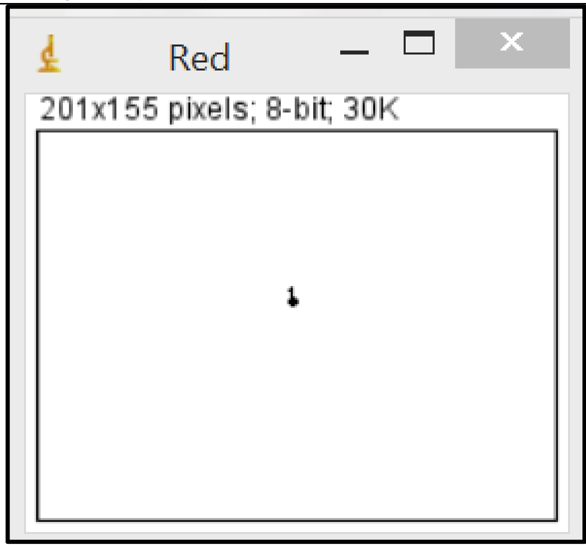
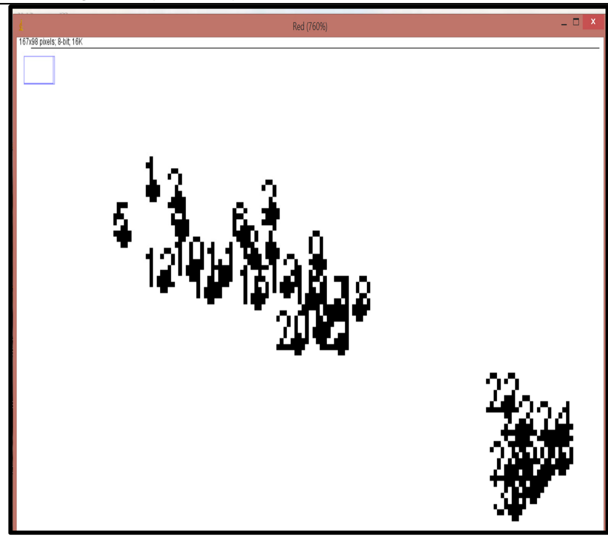
Colony 9 (n = 16)

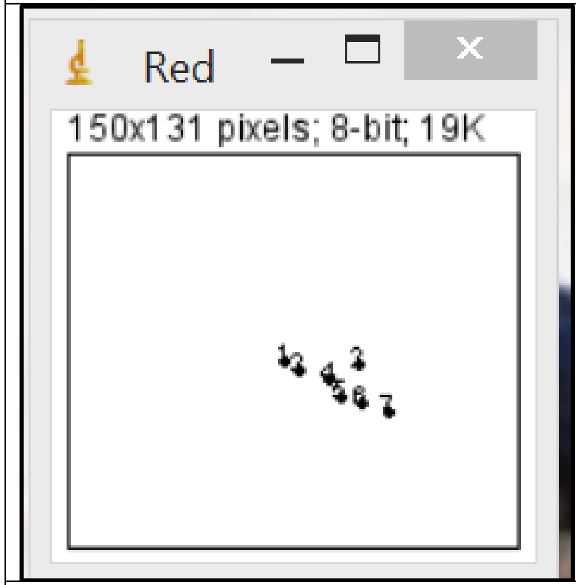
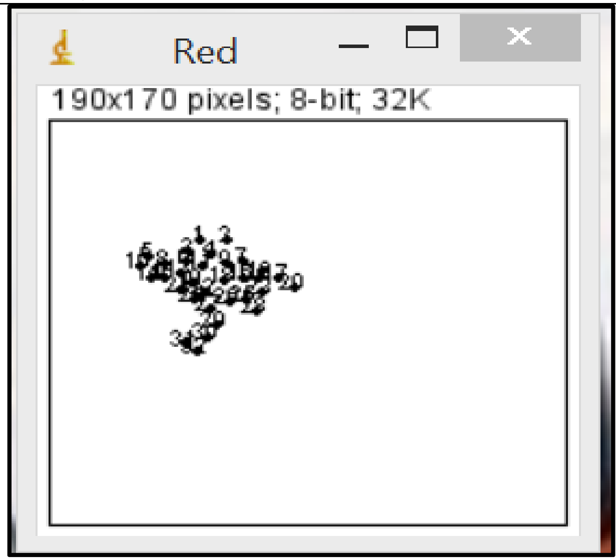
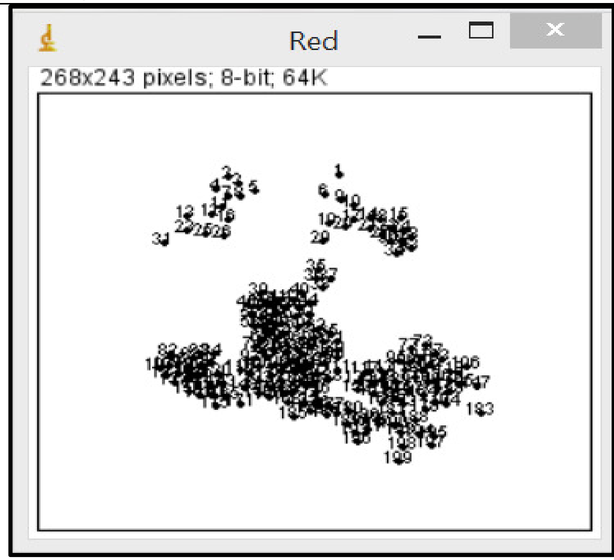
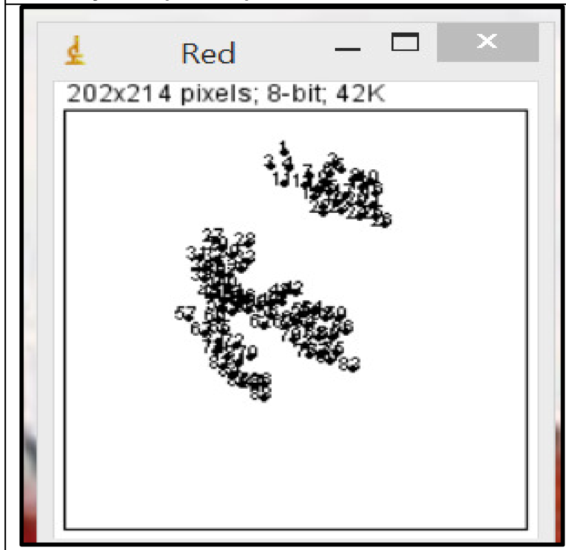
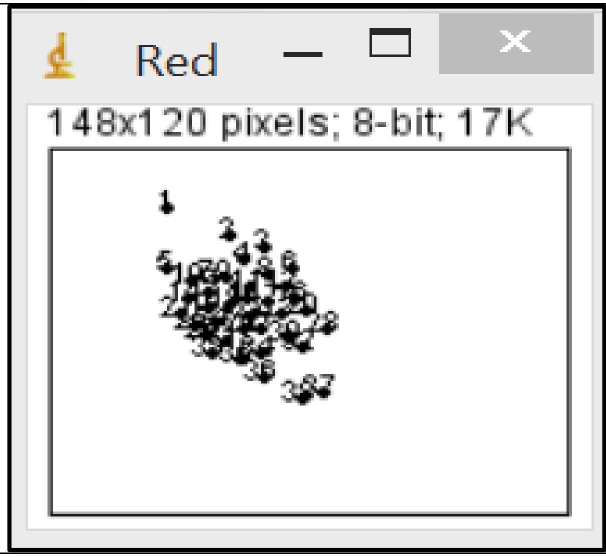
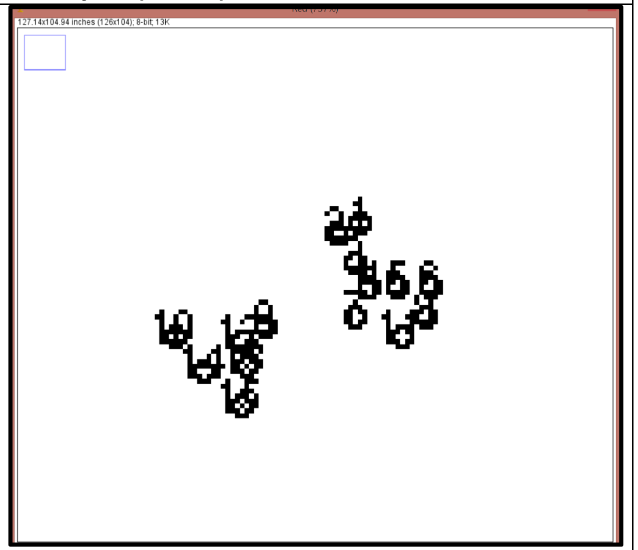


Colony 10 (n = 478)



Colony 11 (n = 402)	Colony 12 (n = 53)	Colony 13 + 14 (n = 333)
		
Colony 13 + 14 (n = as above)	Colony 13 + 14 (n = as above)	
		

Region 2 (Western) Colonies		
Colony 17 (n = 60)	**Colony 18a (n = 42)**	**Colony 18b (n = 60)**
		
Colony 20a (n = 82)	**Colony 20b (n = 1)**	**Colony 20c (n = 26)**
		

Colony 21 (n = 7)	Colony 22 (n = 33)	Colony 23 (n=199)
		
Colony 24a (n = 88)	**Colony 24b (n = 38)**	**Colony 27 (n = 15)**
		

Colony 29 (n = 970)

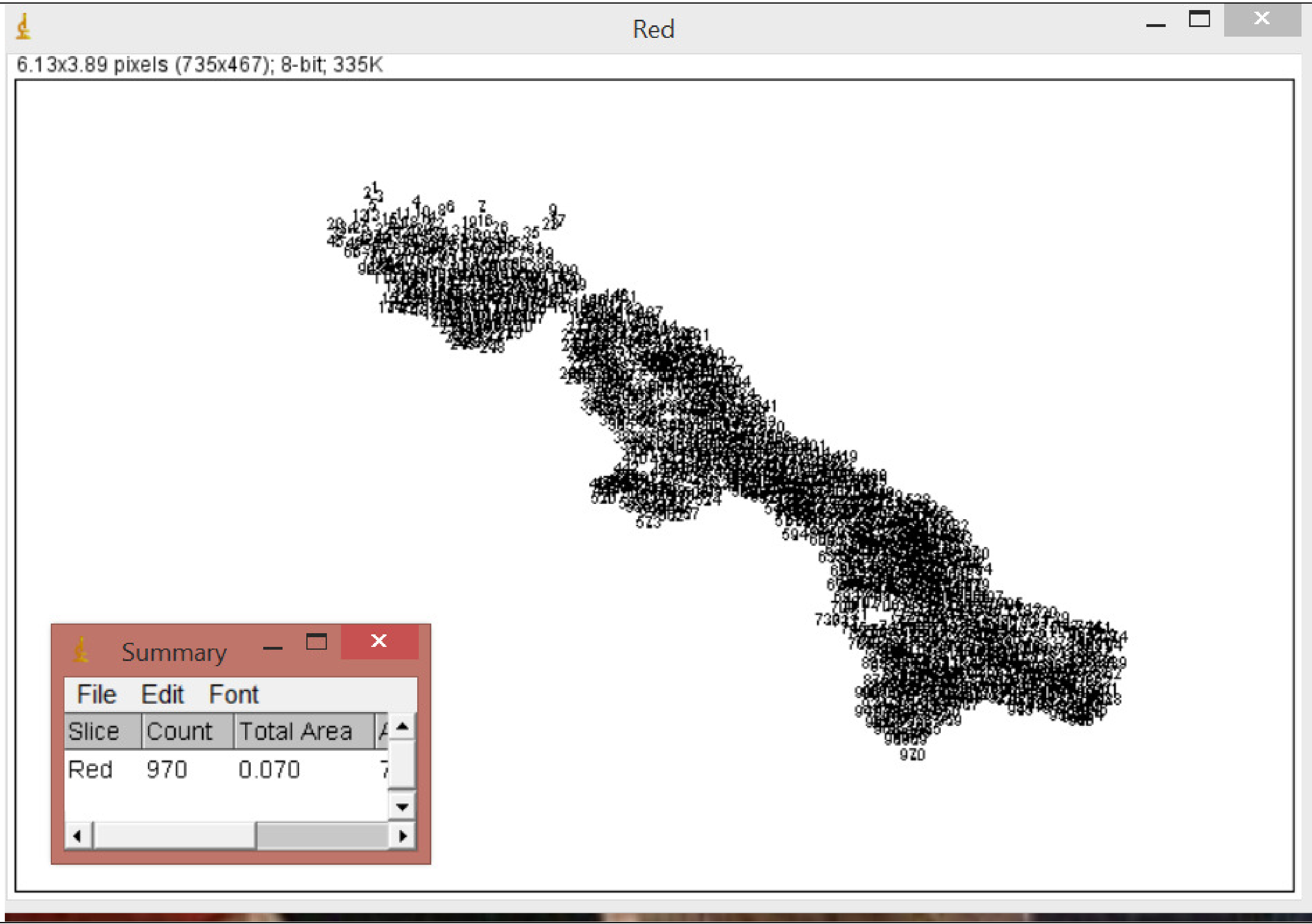


Table 8-a Accuracy & Time Analysis of Comparable Colonies of Less than 250 Identified Nests

COLONY NUMBER	US AMLR 2013-14 RESULTS[a]	MANUAL COUNTING RESULTS	ACCURACY: MANUAL v. US AMLR DATA	AVERAGE [1] TIME PER NEST IDENTIFIED (s)	SEMI-AUTOMATED COUNTING RESULTS	ACCURACY: SEMI-AUTOMATED v. US AMLR DATA	AVERAGE TIME [1] PER NEST IDENTIFIED (s)
5	163	156	95.71%	1.56	156	95.71%	0.64
6	130	116	89.23%	1.42	116	89.23%	2.26
8	168	114	67.86%	1.16	115	68.45%	2.32
9	30	16	53.33%	1.96	16	53.33%	0.88
12	53	53	100%	1.07	53	100%	2.38
17	56	60	93.3%	1.00	60	93.3%	3.33
18	135	102	75.56%	1.51	102	75.56%	2.74
20	125	113	90.4%	1.22	109	87.2%	4.06
21	7	7	100%	3.57	7	100%	14.75
22	33	32	96.97%	1.56	33	100%	8.7
23	185	199	92.96%	1.13	199	92.96%	1.84
24	99	126	78.57%	1.22	126	78.57%	4.06
27	13	15	86.67%	1.30	15	86.67%	9.51
			Average Accuracy	***Average Time***		***Average Accuracy***	***Average Time***
Totals	1,197	1,109	86.12%	1.51 seconds	1,107	86.24%	4.42 seconds

Key:
[1] Time in seconds

Table 8-b Accuracy & Time Analysis of Comparable Colonies of 250 or More Identified Nests

COLONY DESCRIPTOR	US AMLR 2013-14 RESULTS[a]	MANUAL COUNTING RESULTS	ACCURACY: MANUAL v. US AMLR DATA	AVERAGE [1] TIME PER NEST IDENTIFIED	SEMI-AUTOMATED COUNTING RESULTS	ACCURACY: SEMI-AUTOMATED v. US AMLR DATA	AVERAGE TIME[1] PER NEST IDENTIFIED
3	740	705	95.27%	1.05	705	95.27%	0.43
10	482	474	98.34%	1.06	478	99.17%	0.57
11	399	402	99.25%	0.83	402	99.25%	0.83
13 + 14	374	334	89.30%	1.01	333	89.04%	1.14
29	938	983	95.42%	1.06	970	96.70%	1.18
			Average Accuracy	***Average Time***		***Average Accuracy***	***Average Time***
Totals	2,933	2,898	95.52%	1.00 second	2,888	95.89%	0.83 seconds

Key:
[1] Time in seconds

Appendix 9.0 Compilation of ImageJ Tables & Outputs for the Quasi-Automated Counting Approach

Table 9-a Quasi-Automatic Results and Comparison with US AMLR Colony Data for the 2013-2014 Season

Colony Number	No. of Threshold Attempts[a]	Total Time Taken to Reach Most Accurate Result[b] (Seconds)	Quasi-Automatic Counting Results	US AMLR 2013-14 Equivalent Results	Colony % Accuracy[c]
Region 1 (Eastern Colonies)					
3	4[ed] 44[e], 40, 42, 43	240	792	740	Accuracy = 93.42%
5	4 29, 35, 31, 30	164	178	163	Accuracy = 91.57%
6	4 47, 42, 44, 45	166	163	130	Accuracy = 79.76%
8	4 29, 35, 31, 30	184	172	168	Accuracy = 97.67%
9	2 34, 37	103	21	30	Accuracy = 70.00%
10	3[ed] 29, 34, 38	246	489	482	Accuracy = 98.57%
11	5[ed] 30[e], 44, 37, 35, 36	249	413	399	Accuracy = 96.61%
12	4[ed] 42, 38, 39, 40	191	62	53	Accuracy = 85.48%
13 & 14	13a: 3[ed] — 31, 27, 25 14: 2[ed] — 32, 29 13b: 4[ed] — 37, 33, 36, 35	13a: 214s 14: 180s 13b: 231s Average 13 + 14 = ~208	13a: 65 14: 288 13b: 49 13 + 14 Colony Totals = 402	374	Accuracy = 93.04%
Region 1 Summary		**Average time per colony = 195s or 0.65s per nest**	**2,692**	**2,539**	**Regional Accuracy of 94.32%**

Region 2 (Western Colonies)					
17	4 43, 40, 42, 43[ed]	253	51	56	Accuracy = 91.07%
18	a: 39, 35, 35 b: 37e, 40, 43	412	102	135	Accuracy = 75.56%
20	aN: 1 39 aS: 4 27, 40, 38, 39 b: 1 44 c: 5 53, 55, 50, 52, 54	aN: 32s aS: 179s b: 82s c: 178 Average = ~118	109	125	Average Accuracy = 87.20%
21	1 38	36	7	7	Accuracy = 100.00%
22	4 37, 34, 35, 36	142	33	33	Accuracy = 100.00%
23	1 37	40	199	185	Accuracy = 92.96%
24	a: 3 52, 48, 50 b: 3 47, 43, 45	(a) 106s (b) 96s 202	a: 88 b: 38 Colony Total = 126	99	Average Accuracy = 78.57%
27	4 27, 32, 37, 44	145	15	13	Average Accuracy = 86.67%
29	5 41, 32, 33, 35, 34	220	970	938	Average Accuracy = 96.70%

Region 2 Summary	**Average time per colony = 174 seconds or 0.97s per nest**	**1,612**	**1,591**	**Regional Accuracy of 98.70%**

Key & Notes:

[a] Number of thresholding attempts.

34 Most accurate threshold tested.

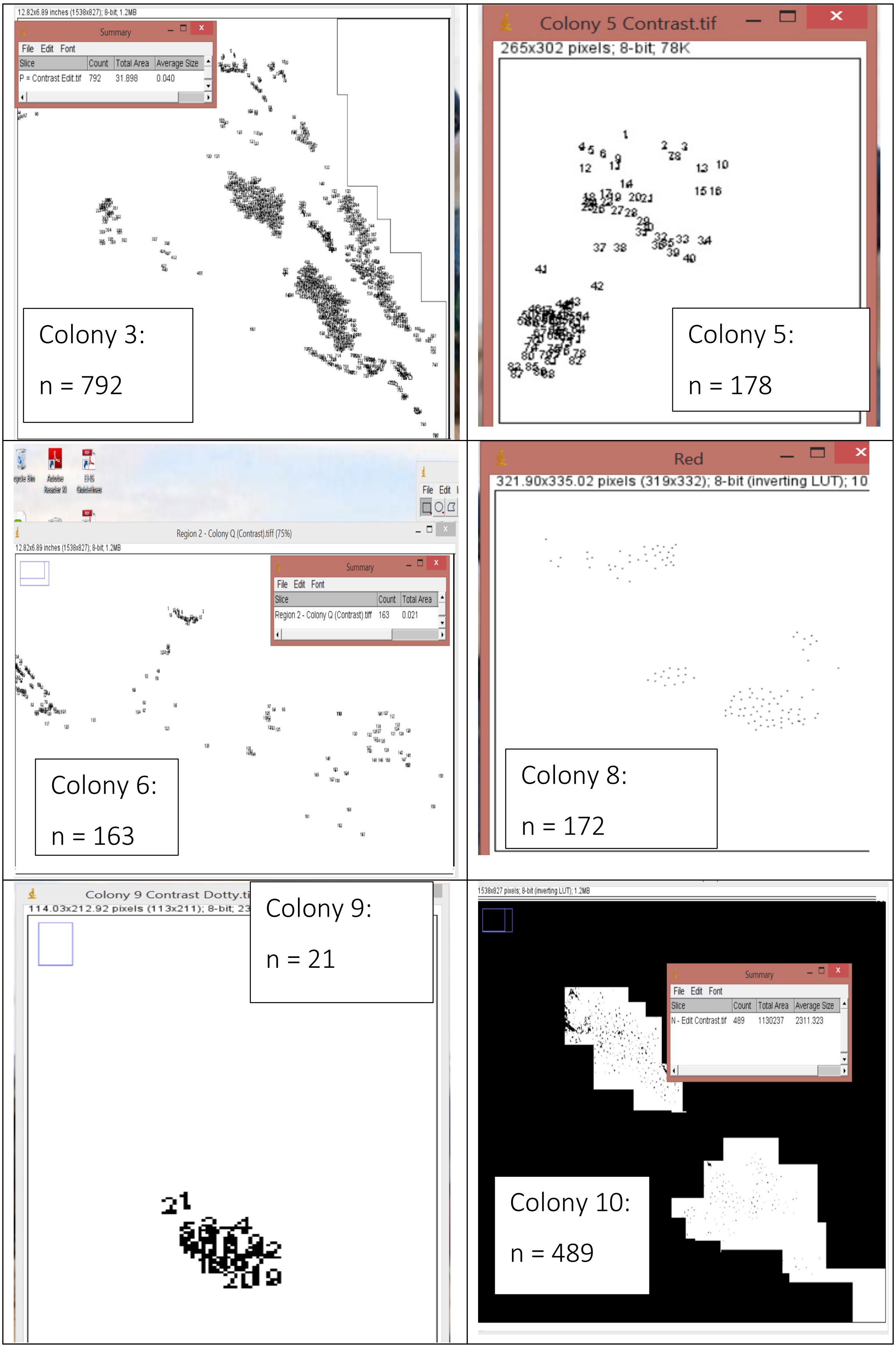
[b] As a comparison with results from US AMLR data for the 2013-14 season.

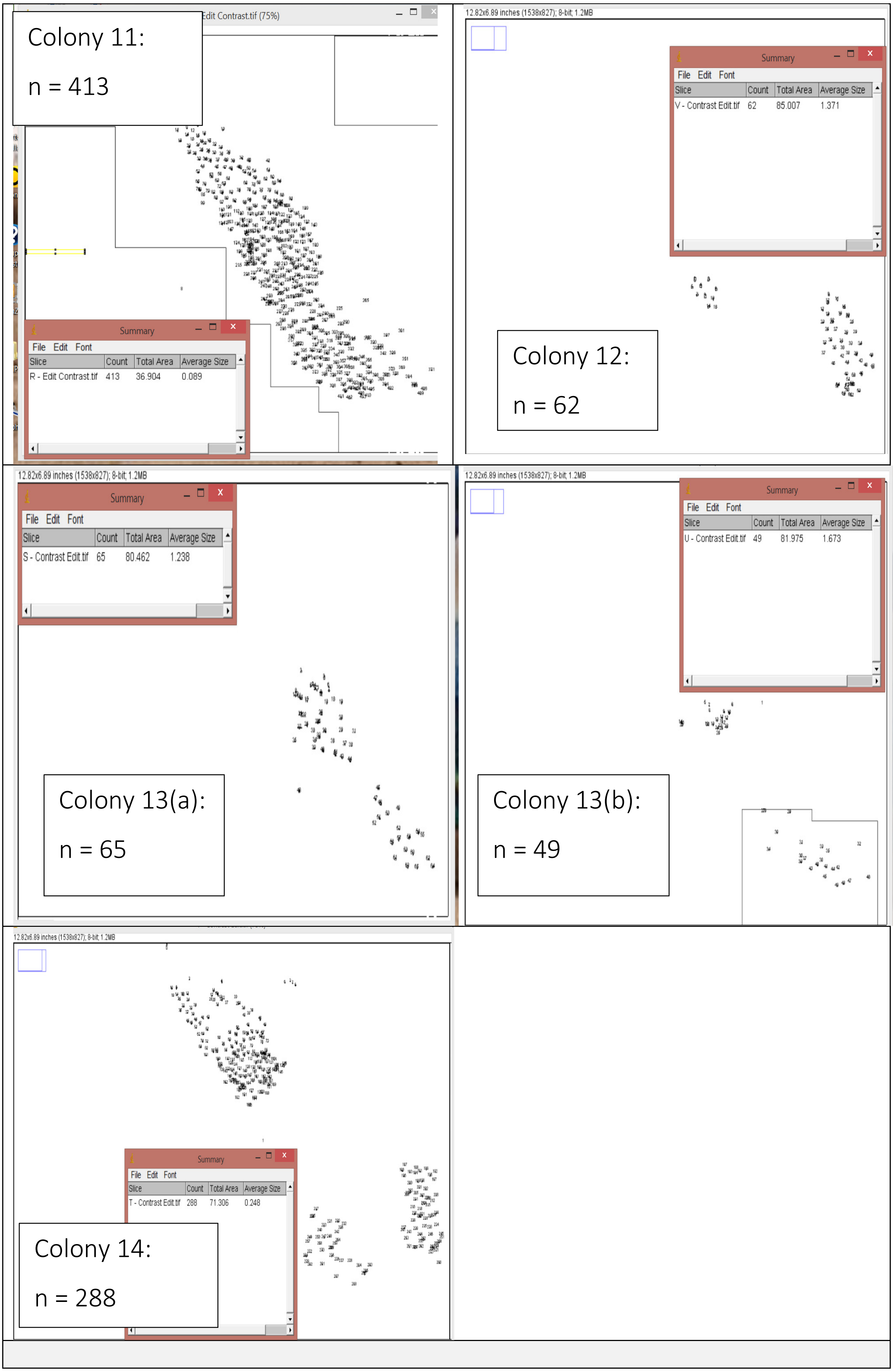
[c] Quasi-automated approach in comparison with US AMLR data.

[ed] [43][ed] = pre-threshold image editing

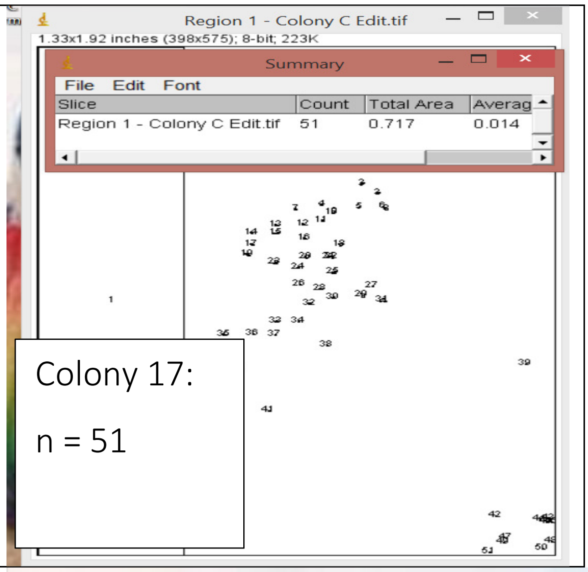
141 Total time taken per colony in seconds.

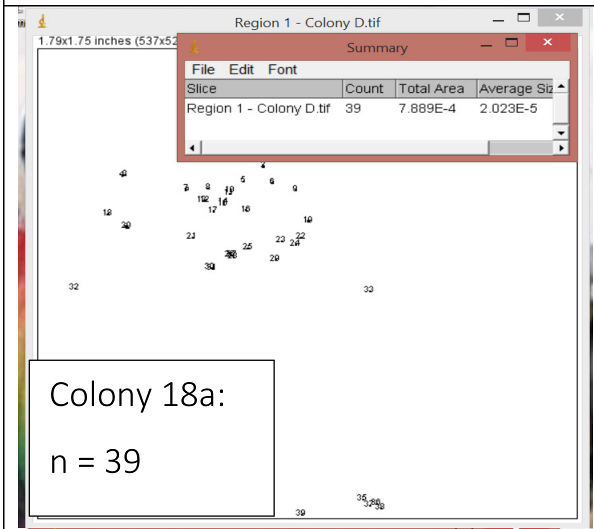
Figure 9-a Compilation of Image J Outputs for the Quasi-Automated Counting of the *Pygoscelid* Colonies at Cape Shirreff

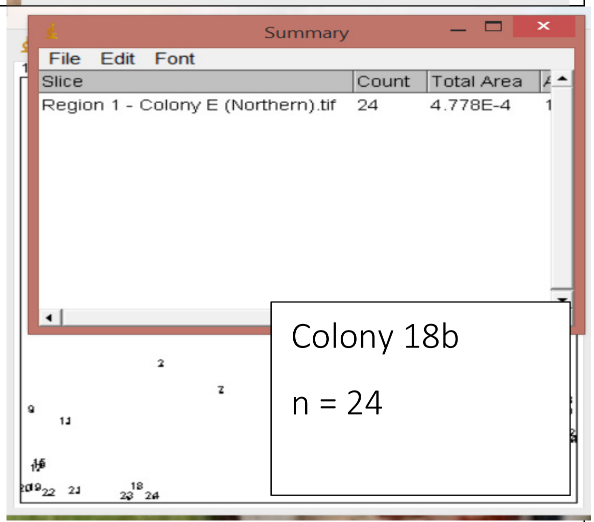


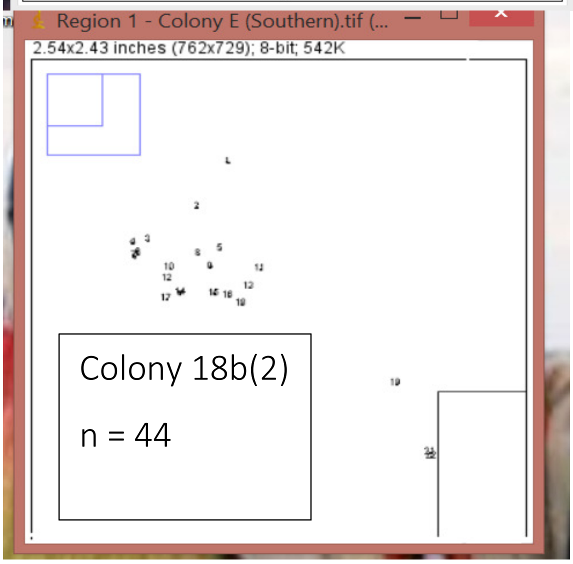

Colony 11:
n = 413
Summary
File Edit Font
Slice Count Total Area Average Size
R - Edit Contrast.tif 413 36.904 0.089
12.82x6.89 inches (1538x827); 8-bit; 1.2MB
Summary
File Edit Font
Slice Count Total Area Average Size
V - Contrast Edit.tif 62 85.007 1.371
Colony 12:
n = 62
12.82x6.89 inches (1538x827); 8-bit; 1.2MB
Summary
File Edit Font
Slice Count Total Area Average Size
S - Contrast Edit.tif 65 80.462 1.238
Colony 13(a):
n = 65
12.82x6.89 inches (1538x827); 8-bit; 1.2MB
Summary
File Edit Font
Slice Count Total Area Average Size
U - Contrast Edit.tif 49 81.975 1.673
Colony 13(b):
n = 49
12.82x6.89 inches (1538x827); 8-bit; 1.2MB
Summary
File Edit Font
Slice Count Total Area Average Size
T - Contrast Edit.tif 288 71.306 0.248
Colony 14:
n = 288

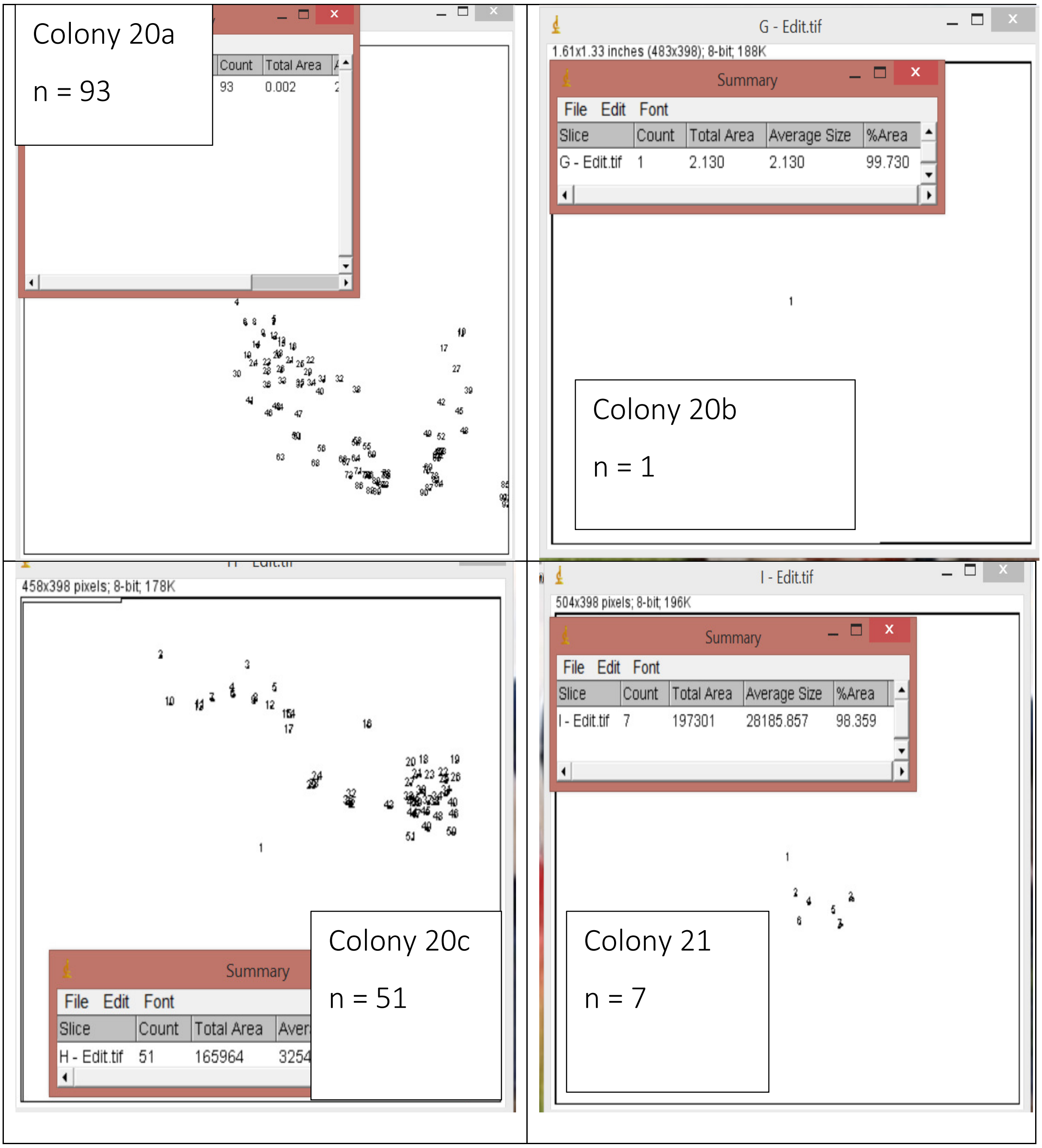
Region 2 (Western) Colonies:

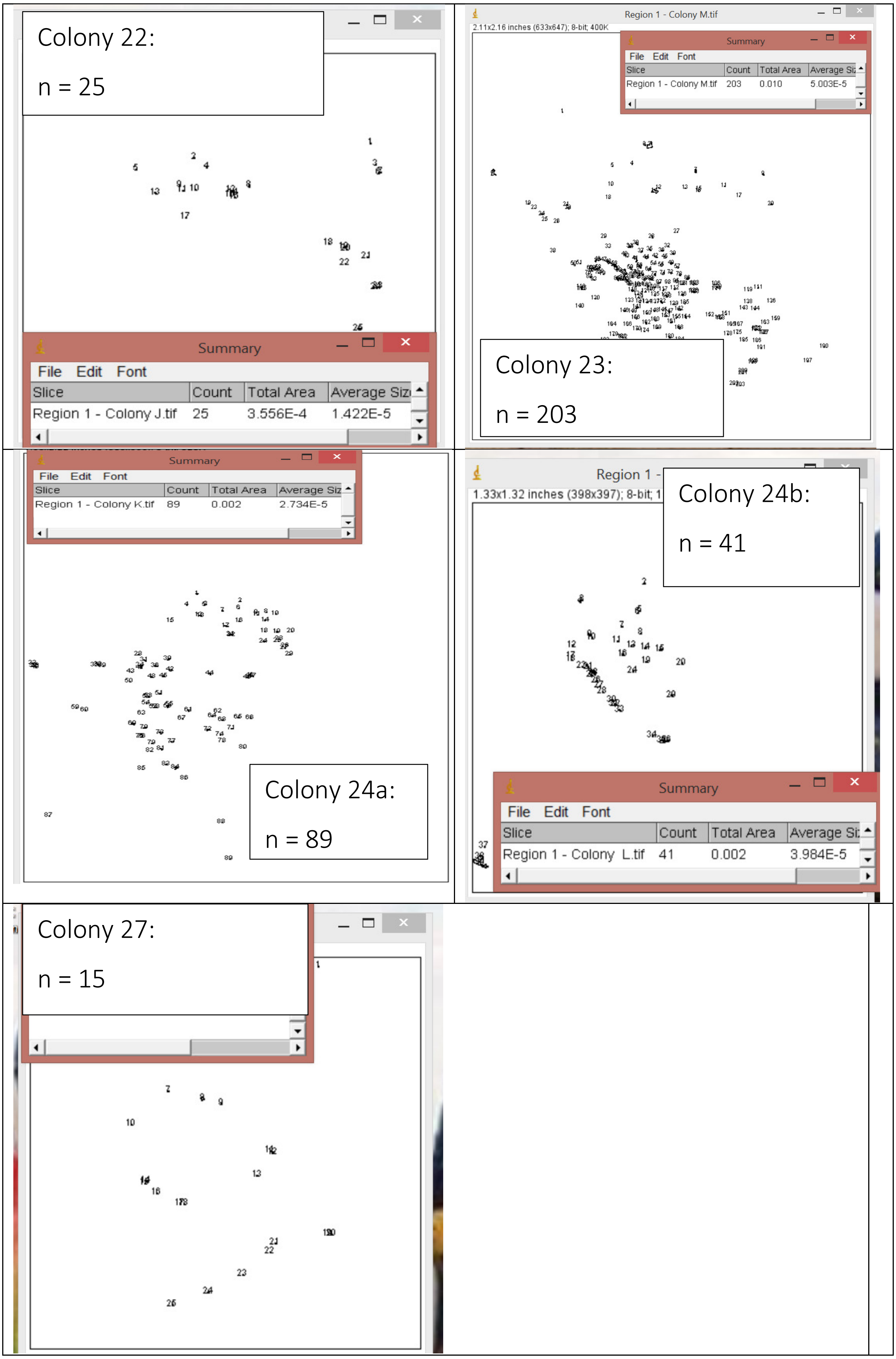


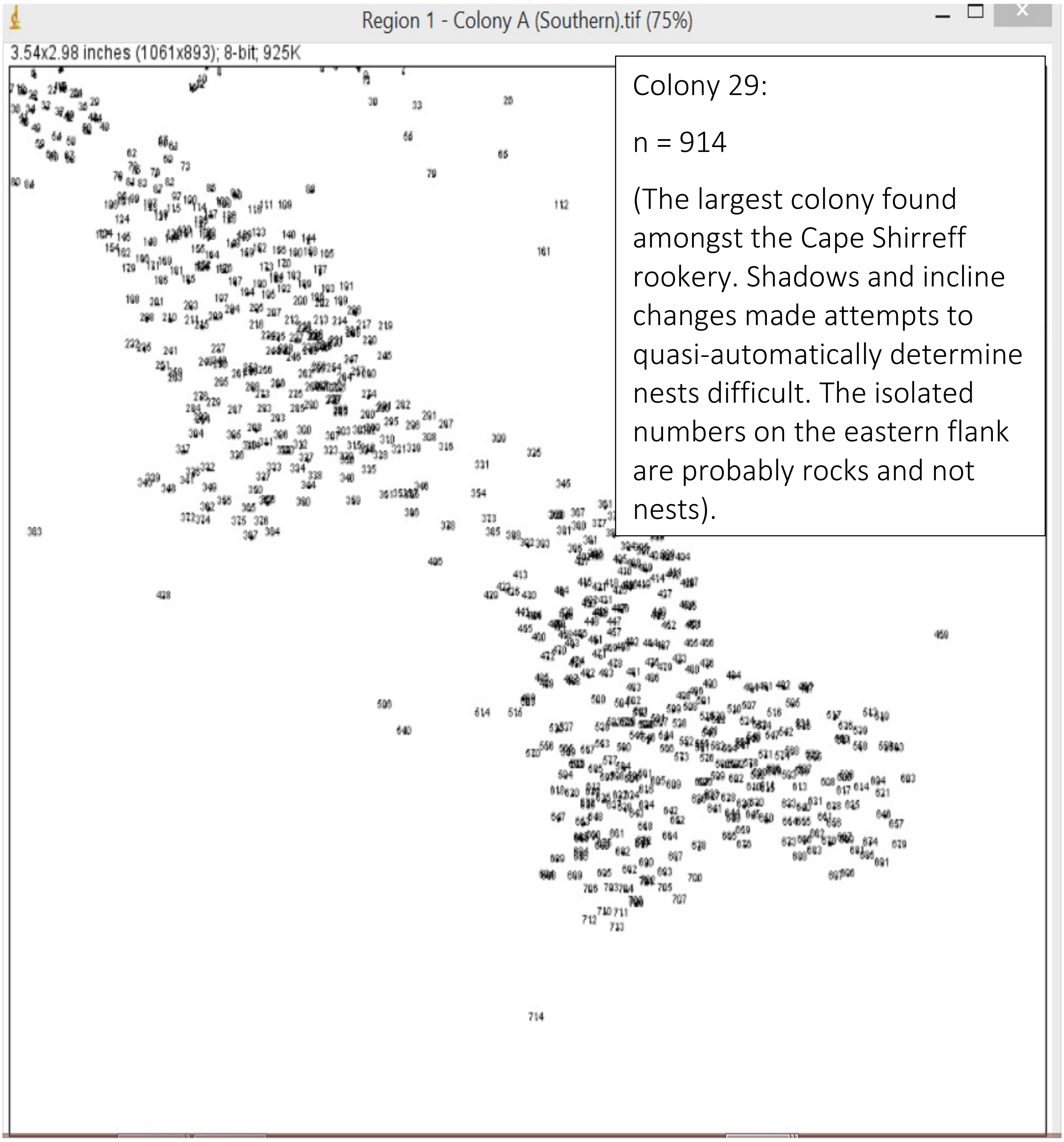







Colony 20a
n = 93
Count
Total Area
93
0.002
G - Edit.tif
1.61x1.33 inches (483x398); 8-bit; 188K
Summary
File Edit Font
Slice Count Total Area Average Size %Area
G - Edit.tif 1 2.130 2.130 99.730
Colony 20b
n = 1
458x398 pixels; 8-bit; 178K
Summary
File Edit Font
Slice Count Total Area Aver
H - Edit.tif 51 165964 3254
Colony 20c
n = 51
I - Edit.tif
504x398 pixels; 8-bit; 196K
Summary
File Edit Font
Slice Count Total Area Average Size %Area
I - Edit.tif 7 197301 28185.857 98.359
Colony 21
n = 7


Colony 22:
n = 25
Summary
File Edit Font
Slice Count Total Area Average Size
Region 1 - Colony J.tif 25 3.556E-4 1.422E-5
Region 1 - Colony M.tif
2.11x2.16 inches (633x647); 8-bit; 400K
Summary
File Edit Font
Slice Count Total Area Average Size
Region 1 - Colony M.tif 203 0.010 5.003E-5
Colony 23:
n = 203
Summary
File Edit Font
Slice Count Total Area Average Size
Region 1 - Colony K.tif 89 0.002 2.734E-5
Colony 24a:
n = 89
1.33x1.32 inches (398x397); 8-bit;
Colony 24b:
n = 41
Summary
File Edit Font
Slice Count Total Area Average Size
Region 1 - Colony L.tif 41 0.002 3.984E-5
Colony 27:
n = 15



Colony 29:

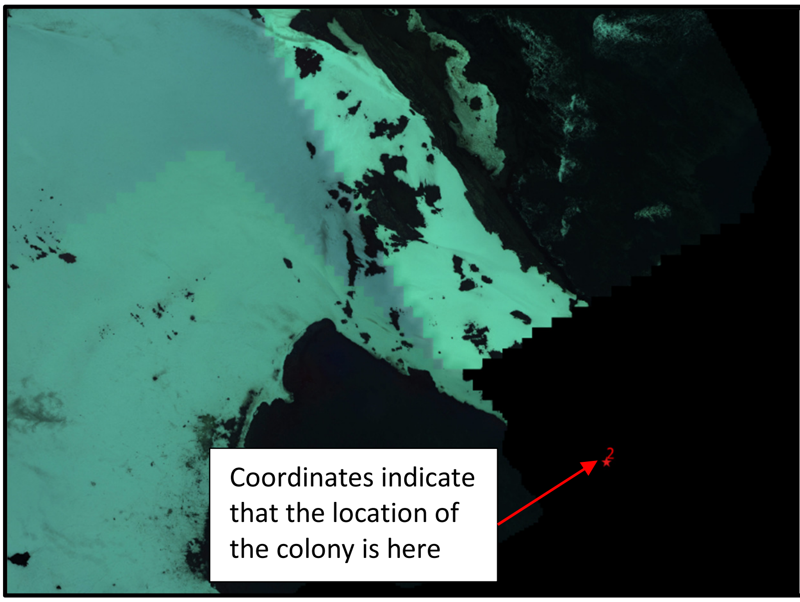
n = 914

(The largest colony found amongst the Cape Shirreff rookery. Shadows and incline changes made attempts to quasi-automatically determine nests difficult. The isolated numbers on the eastern flank are probably rocks and not nests).

Appendix 10.0 Cape Shirreff Rookery: Additional Colony Images & Locational Information

The Eastern Colonies

Colony 2

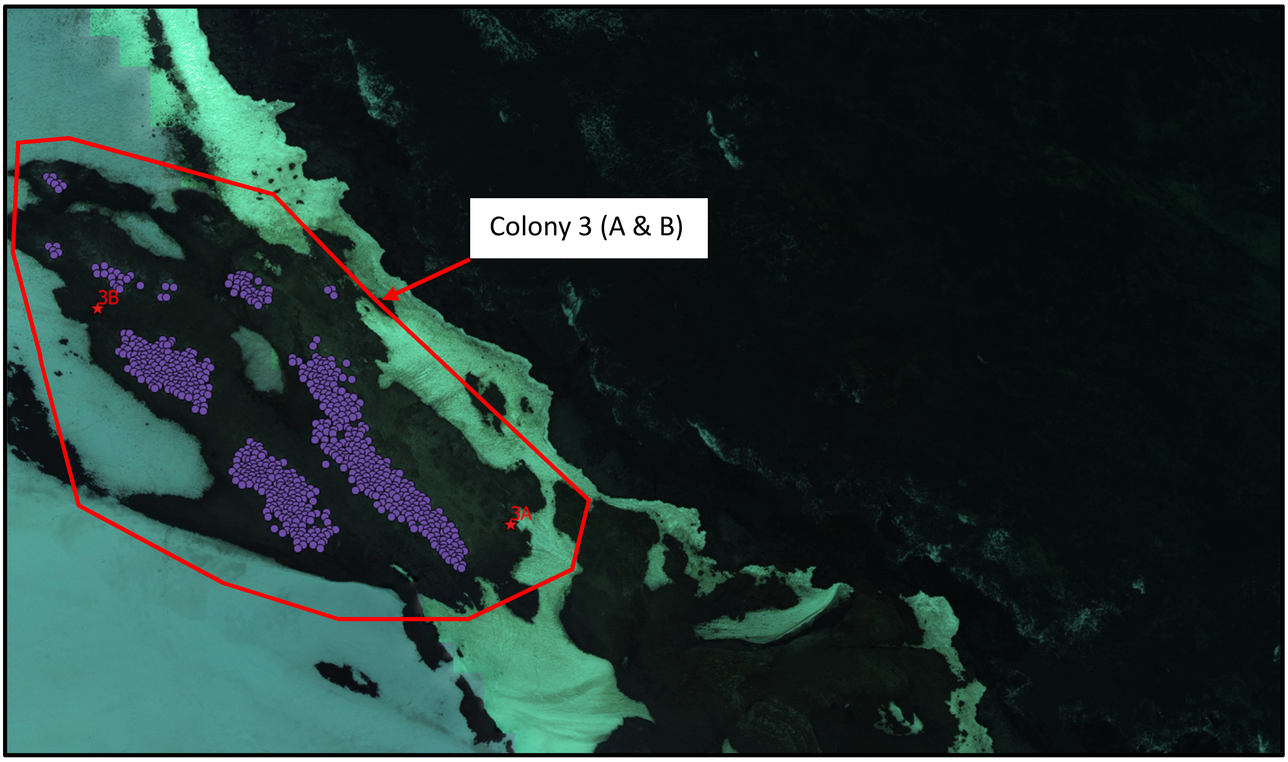


Colony 2 is defined by the US AMLR as a ‘non-disturbance’ colony.

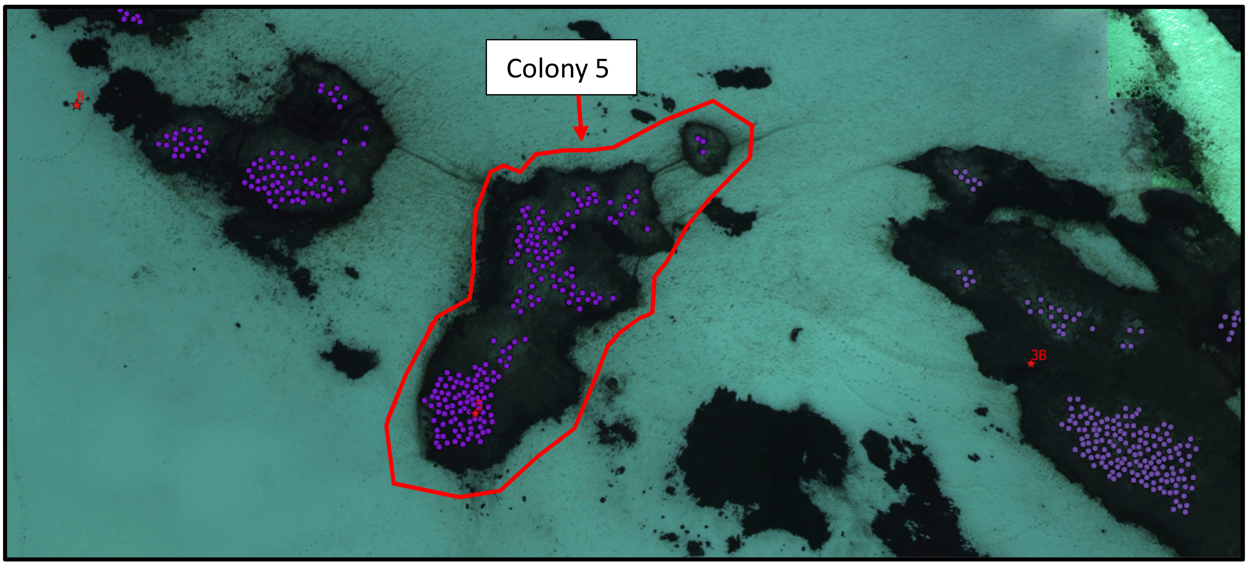
There are no attributable details other than the longitude and latitude pointing to an inshore waters location.

From in-situ ground counting in the 2013-14 season, the number of *Pygoscelid* nests at the colony was 291. Given that I was not able to complete an analysis of this colony, this figure (291) was removed from the calculations.

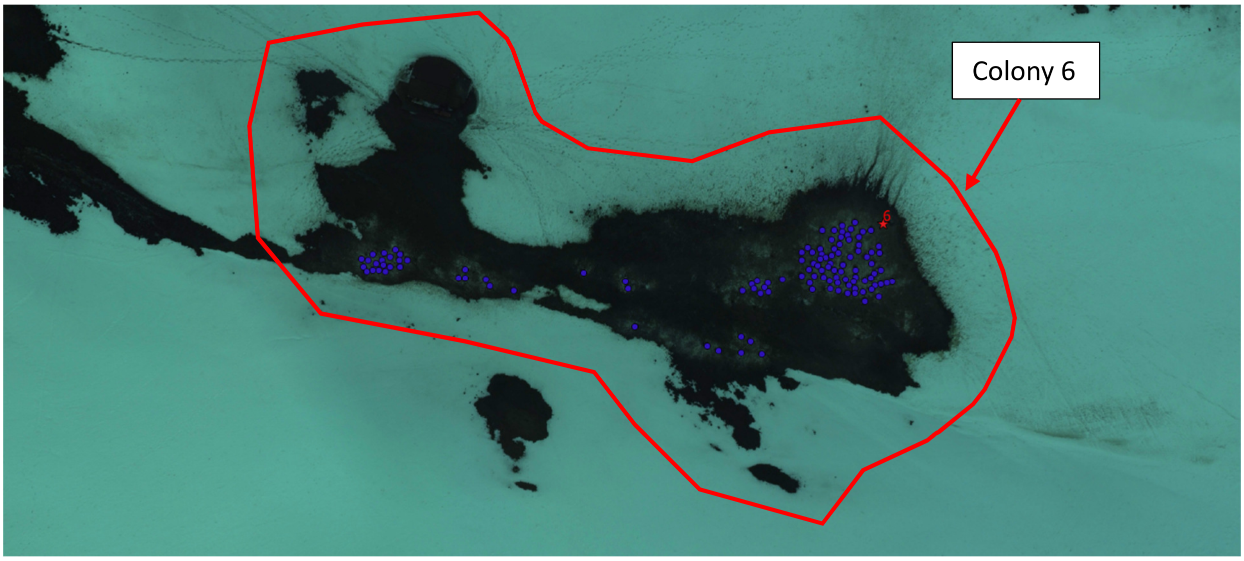
Colony 3A & 3B



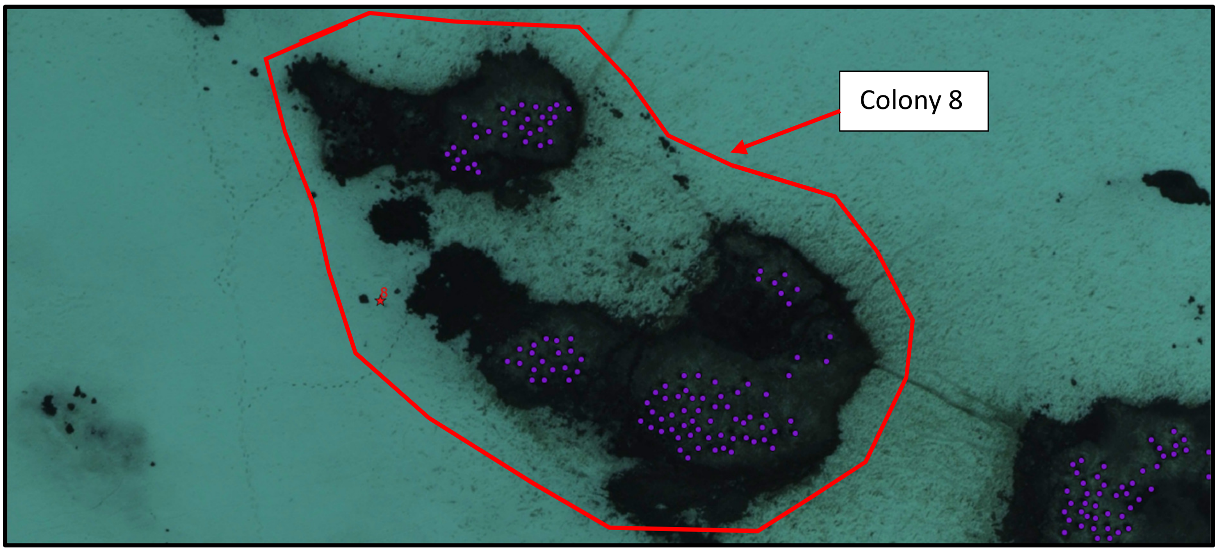
Colony 5



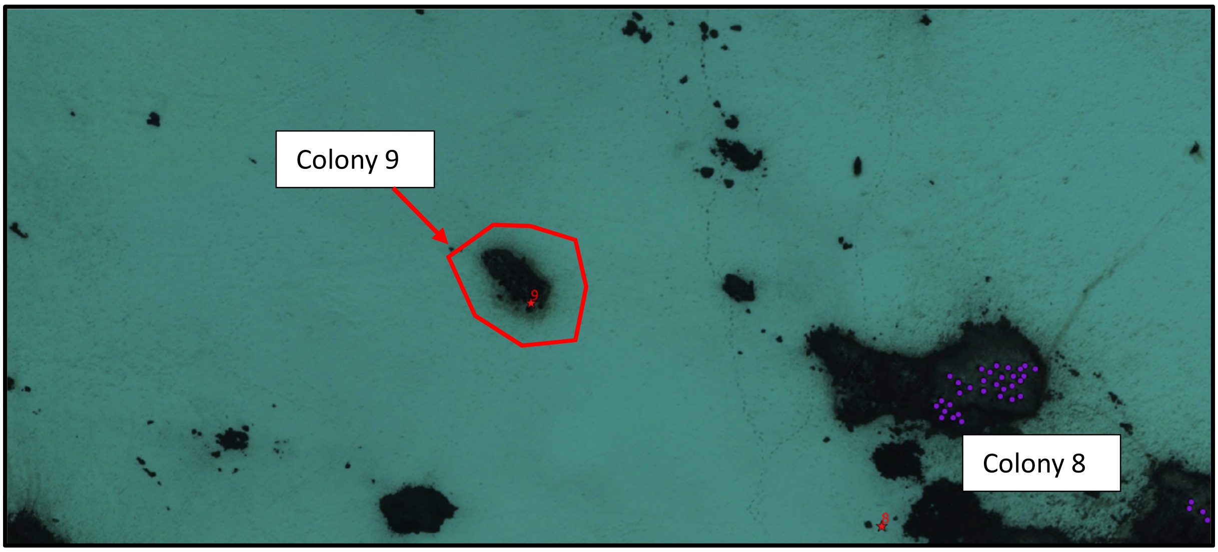
Colony 6



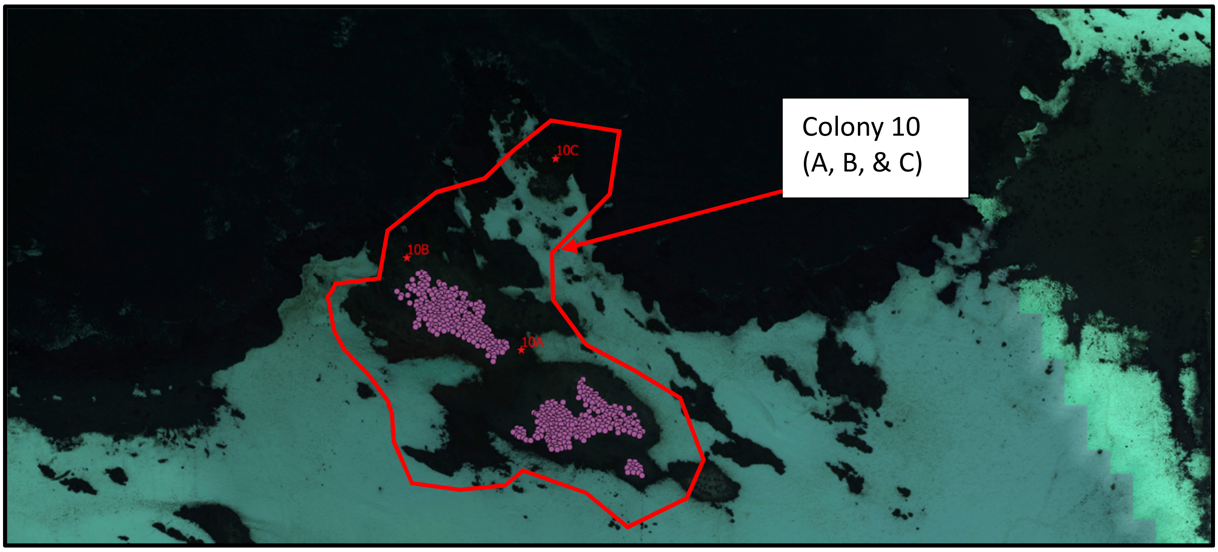
Colony 8



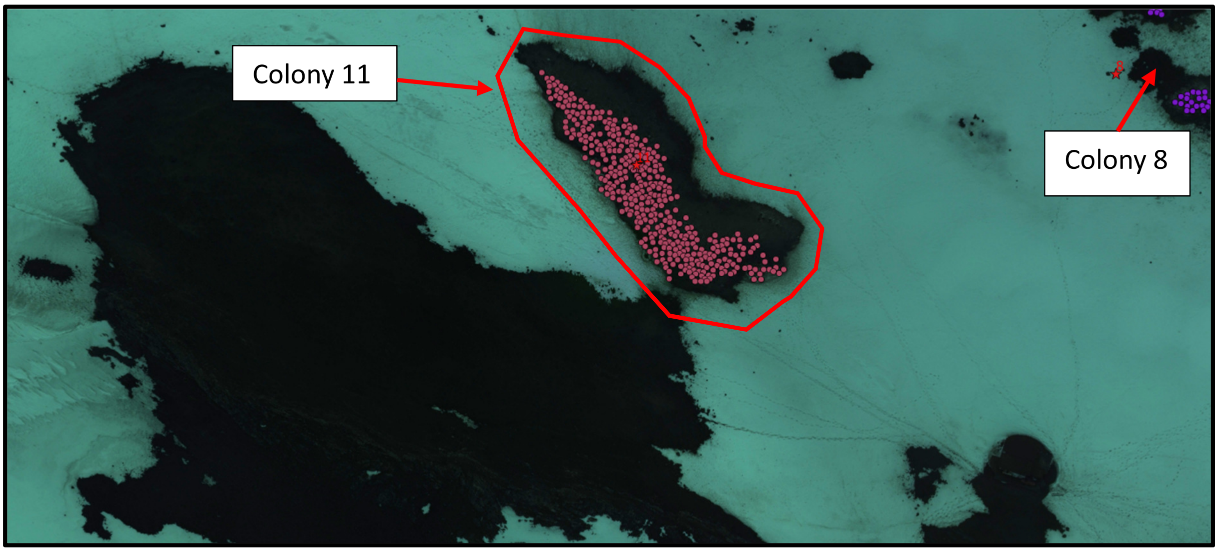
Colony 9



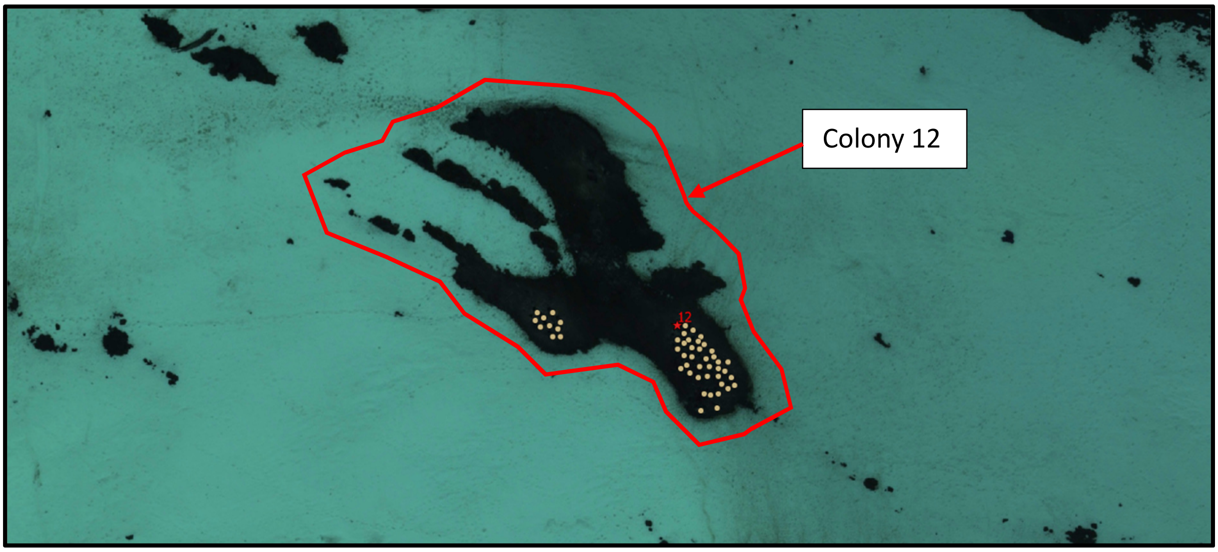
Colony 10



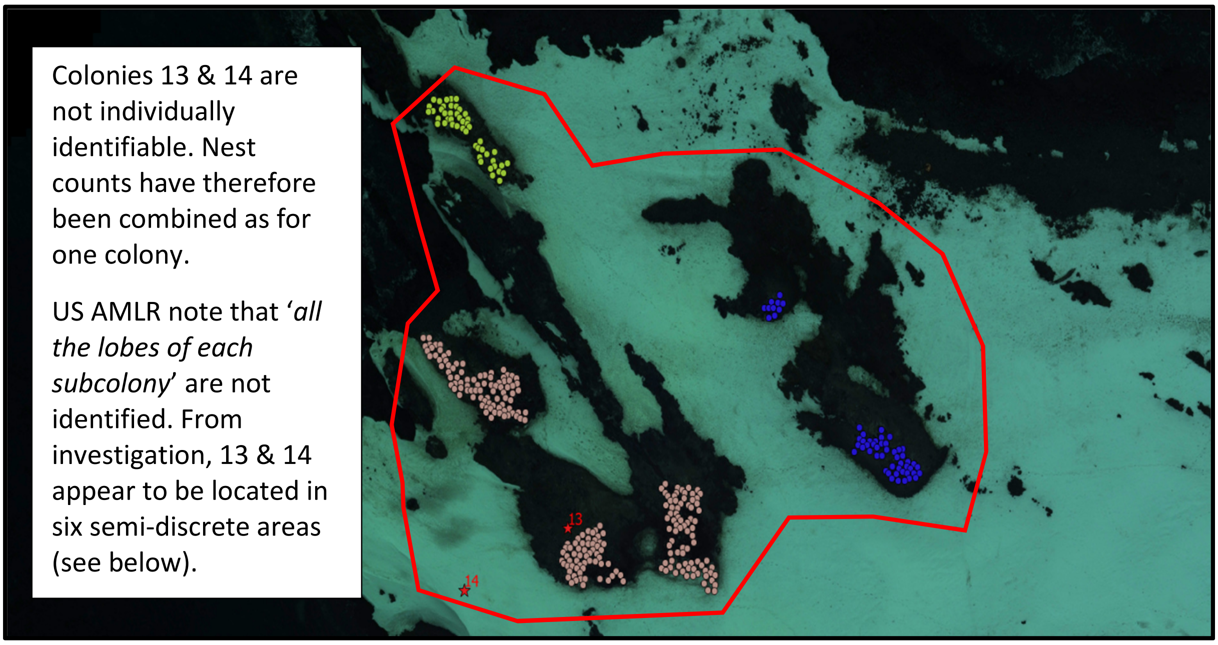
Colony 11



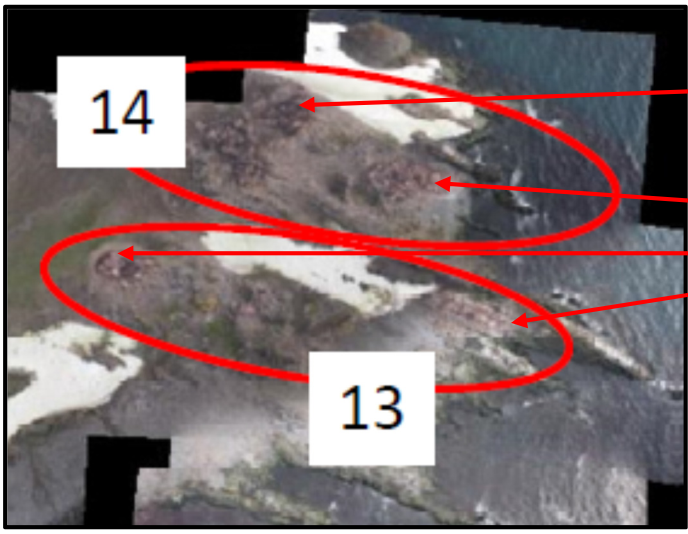
Colony 12



Colonies 13 + 14 Combined



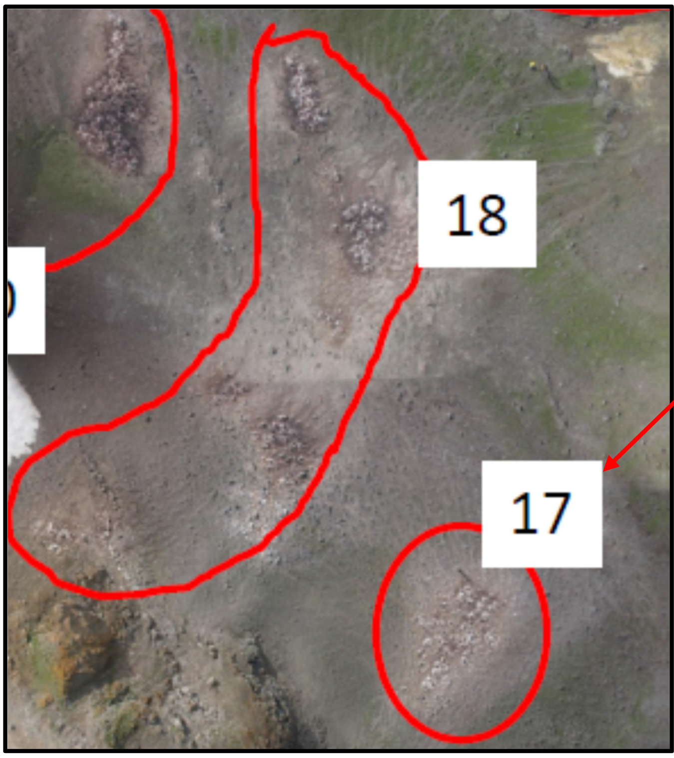
Additional (US AMLR Hexacopter) Imagery for Colonies 13 and 14



Multiple areas clear from UAV imagery, as is the coastal location and distinctive landforms.

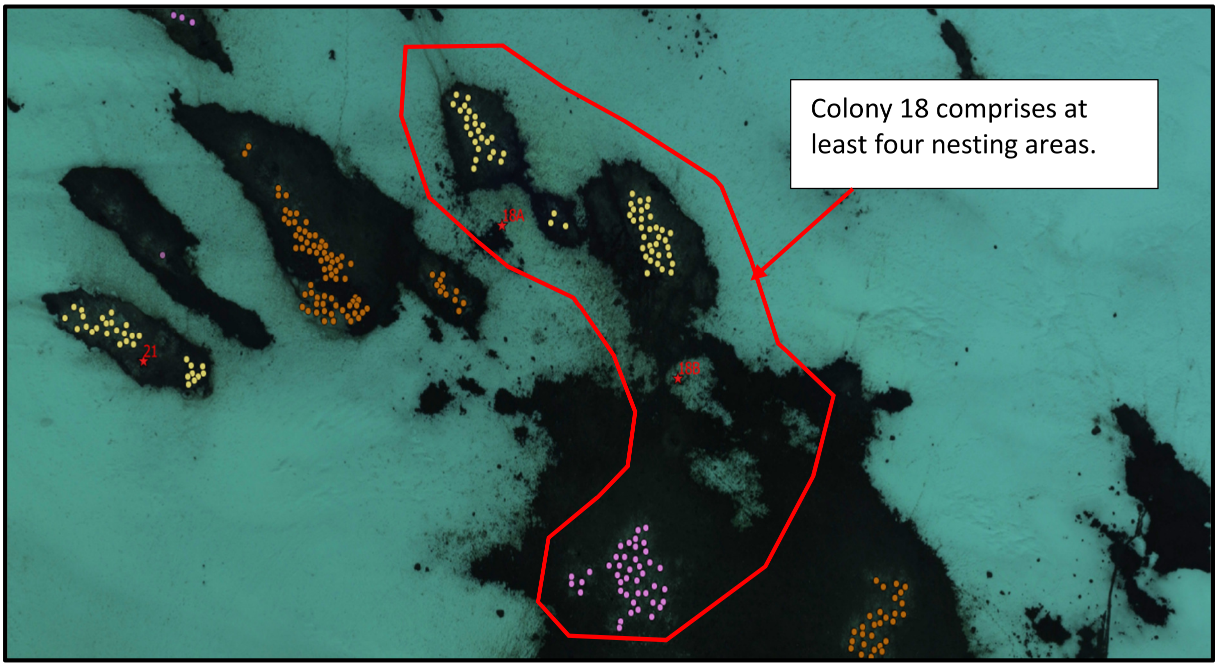
The Western Colonies

Colony 17

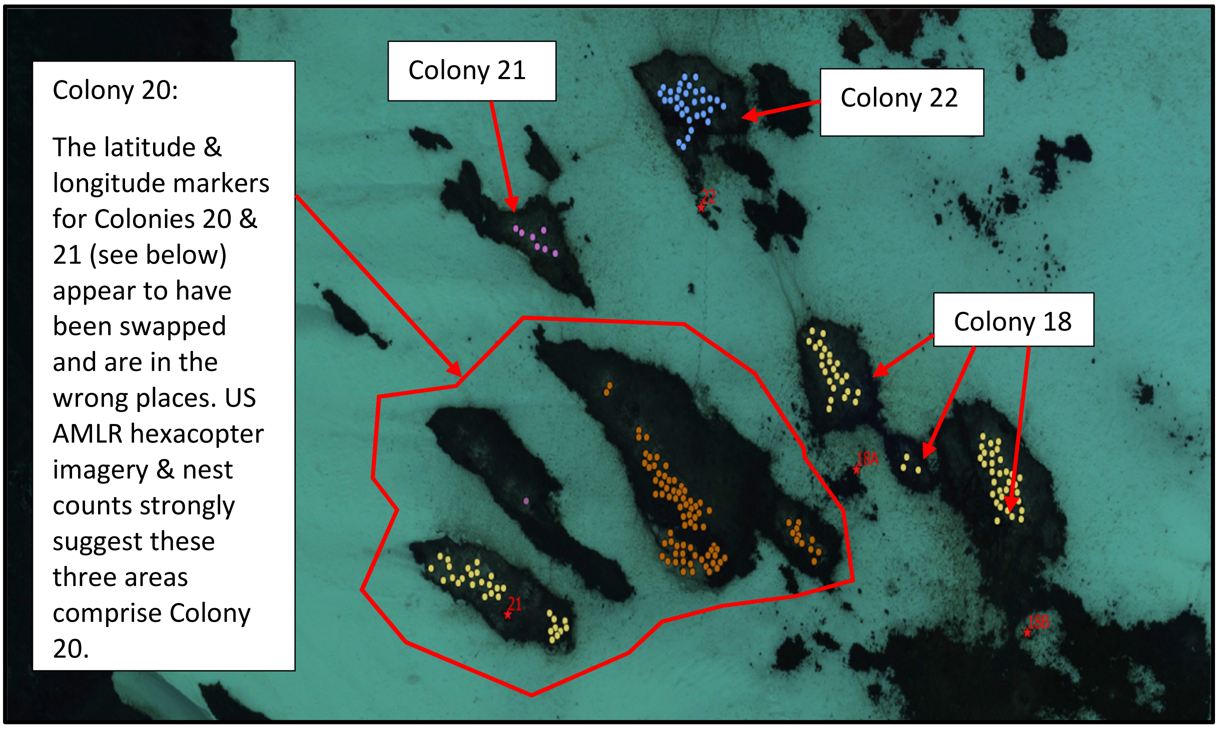


Neither latitudinal nor longitudinal information were available at the time of writing but Colony 17 is clearly marked within the US AMLR 'hexacopter'-derived imagery, and is situated south-south-east of Colony 18.

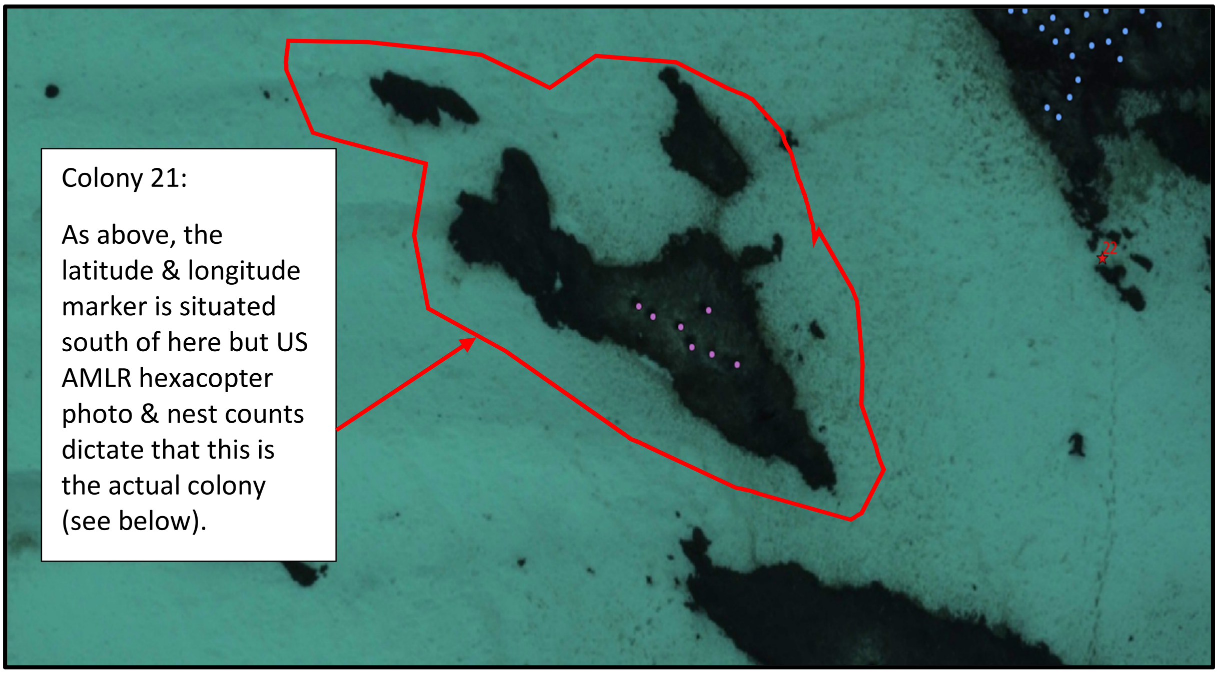
Colony 18



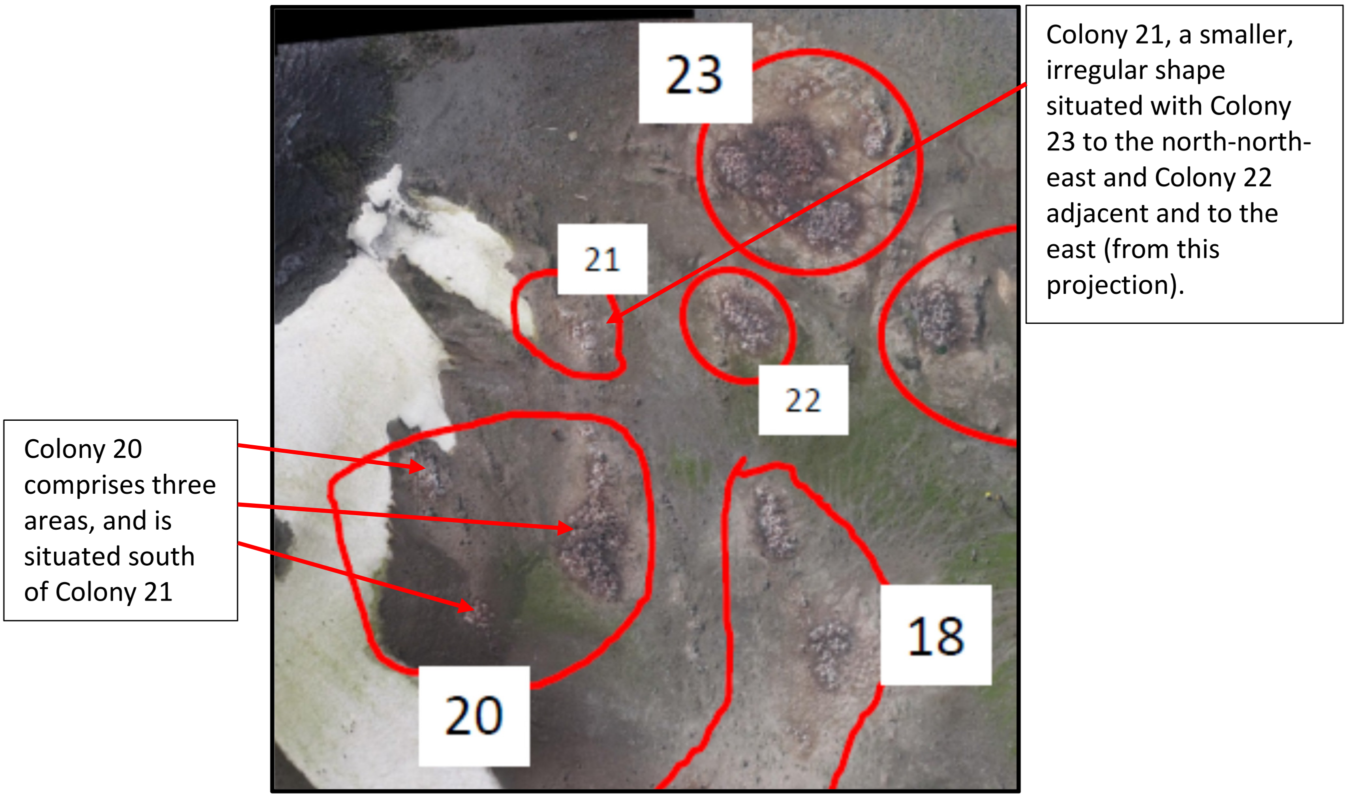
Colonies 20



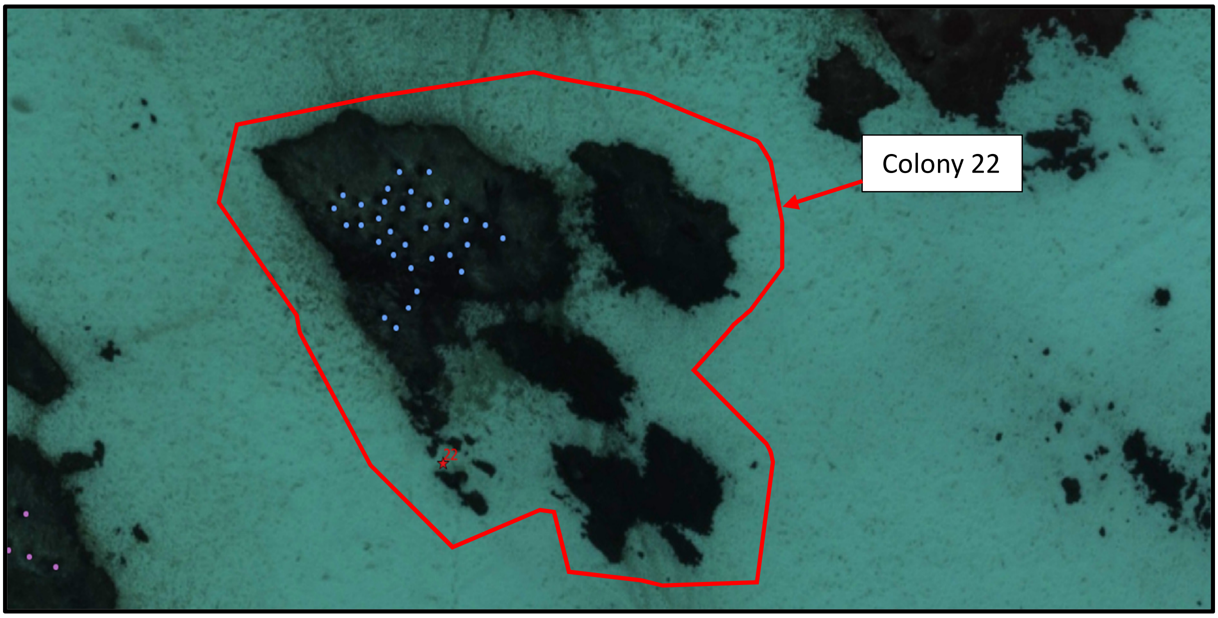
Colony 21



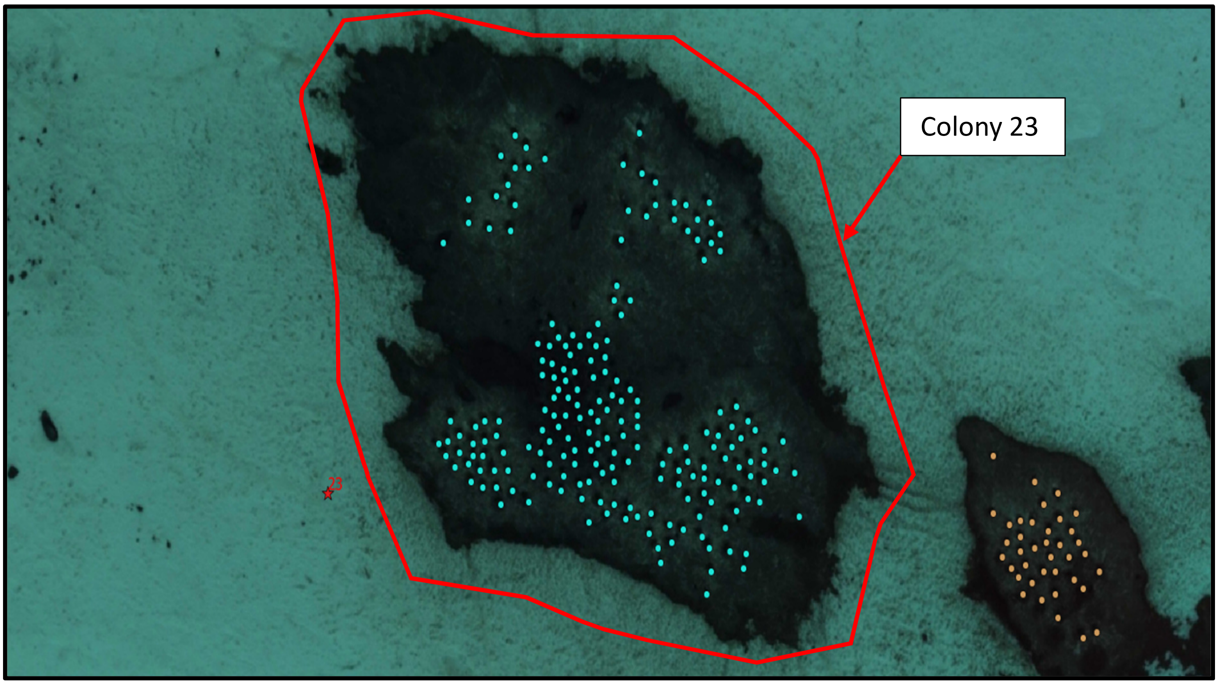
Additional (Hexacopter) Imagery for Colonies 20 and 21



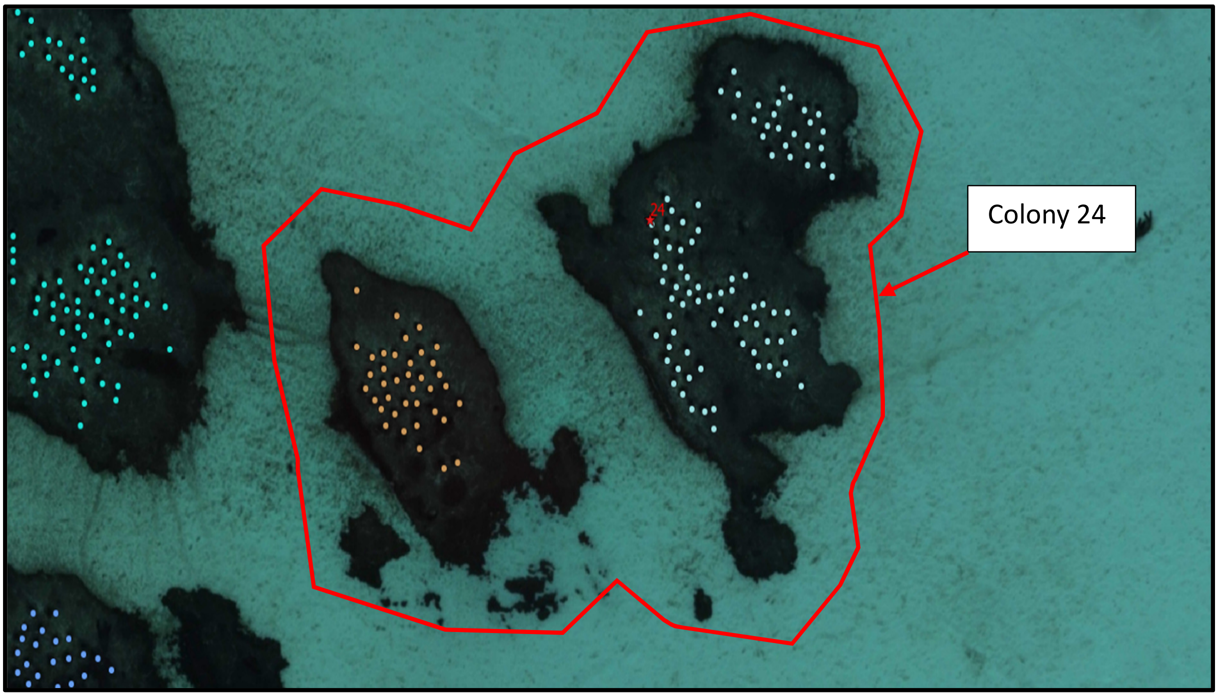
Colony 22



Colony 23



Colony 24



Colony 27

Appendix 11 Geo-Referencing Coordinates

MultiSpec was used to provide the geo-referenced capability required of the investigations. A simple equation is needed here. The first step is the opening of the parent image in MultiSpec, from which the following information is required for the equation:

- the Grid Coordinate System: here, UTM-WGS84;
- the Zone: 21S;
- the 'x' coordinate number for the top-left pixel of the image: 72.654 (x_0 in the equation);
- the 'y' coordinate number for the top-left pixel: 40.363 (y_0); and,
- the horizontal (p_x) and vertical (p_y) pixel sizes, which should be identical: 0.141.

With the equation for determining the geo-referenced coordinates for *x* (here, the 'Eastings') and *y* (the 'Northings') of a pixel that has pixel coordinates X and Y (from ImageJ, above):

$$x = x_0 + p_x X$$

$$y = y_0 - p_y Y$$

which, in our example, equates to the Eastings and Northings detailed in table A, below, with figure A illustrating how such geo-referenced material may be represented within a GIS system (QGIS, here) to show the real-world location of the nests and which may be used for subsequent analysis and shared with other interested parties.

Table A Geo-Referenced Output Examples

X Coordinate	Y Coordinate	Eastings	Northings
ImageJ Coordinates		**Geo-Referenced Object Locations**	
72.654	40.363	304207.7312	3068597.285
67.608	42.381	304207.0197	3068597.000
71.645	48.436	304207.5889	3068596.147
74.672	53.481	304208.0158	3068595.435
80.727	53.481	304208.8695	3068595.435
87.79	53.481	304209.8654	3068595.435
71.645	59.536	304207.5889	3068594.581
86.781	59.536	304209.7231	3068594.581

Figure A Example GIS Output

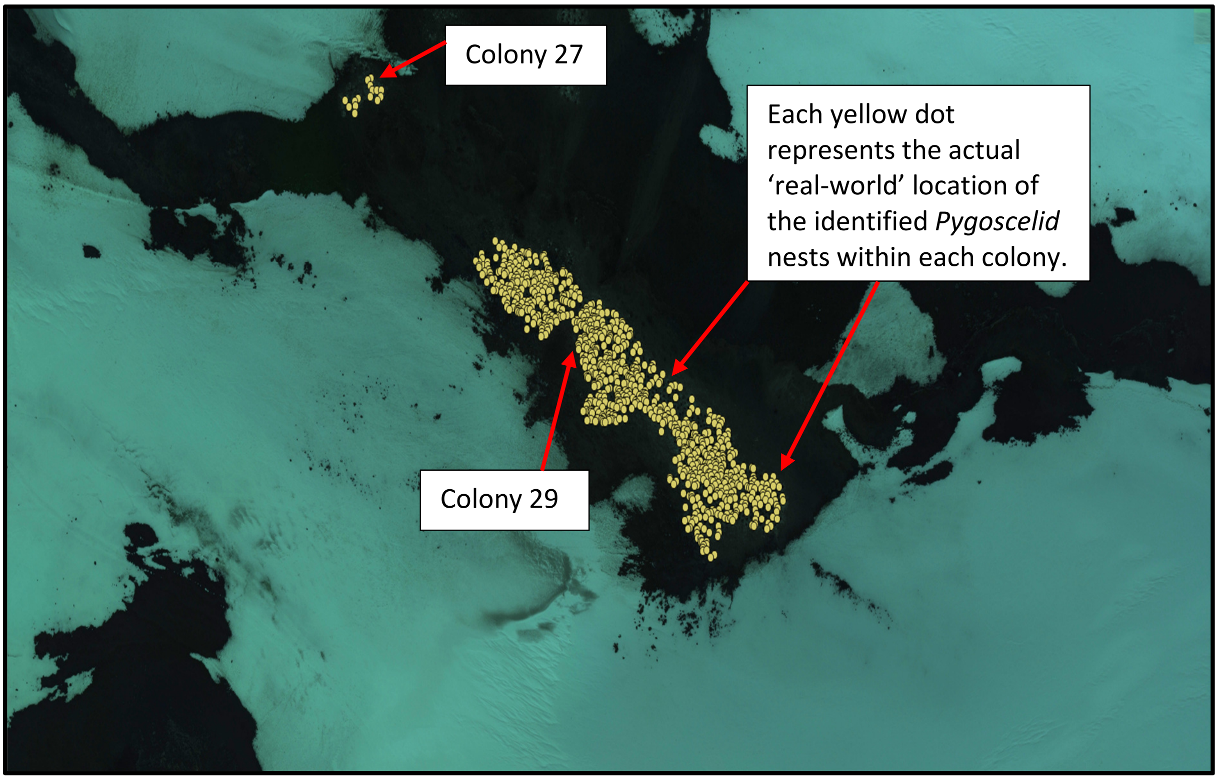


Table B GNU Octave 'Distances' Programme

GNU Programme	Comment
`a=load('datain.txt');` `tic`	The input filename is 'datain.txt'.
`n=rows(a);`	Count the number of data values…

`for j=1:n`
`b=a(j,:);`
`c=a-repmat(b,n,1);`
	…for each data point P.

`d=sumsq(c,2);`	Vector d contains the squared distance from P to all data points in order.

`d2=sort(d);`
`dmin(j)=sqrt(d2(2));`
`endfor`
	d2 is vector d sorted into ascending order. The first value in this vector is guaranteed to be zero because the nearest data point to P is P itself. Thus, the second value in the array will be the (square of) the distance to the nearest data point that is not P.

`a(:,3)=dmin;`	Add the calculated minimum distance to the original data.
`dlmwrite('dataout.txt',a);`	Save the data as the file 'dataout.txt'.
`tex=toc`	Reports the time taken to analyse all the data points (a non-essential function).

As an example, from the use of the above programme, the nest identified at the coordinates in red, (table B), is situated 76.65cm (0.7665m) from its nearest neighbor; whilst the nest identified in blue is situated 95.48cm (0.9548m) from its nearest neighbor:

Table B Geo-Referenced Output Examples with Distances

Eastings	Northings	Distances (in Metres)
Geo-Referenced Object Locations		
304207.7312	3068597.285	0.766457598
304207.0197	3068597	0.766457598
304207.5889	3068596.147	0.830173241
304208.0158	3068595.435	0.830173241
304208.8695	3068595.435	0.8537
304209.8654	3068595.435	0.865774388
304207.5889	3068594.581	0.954756309
304209.7231	3068594.581	0.865774388

Appendix 12 Distance Calculations with Standard Deviations

Congeneric		Congeneric		Gentoo		Congeneric		Chinstrap		Congeneric		Chinstrap		Chinstrap		Chinstrap		Gentoo		Gentoo		Congeneric		Gentoo		Gentoo		Congeneric		Gentoo		Chinstrap		Chinstrap
Colony 3	Mean	Colony 5	Mean	Colony 6	Mean	Colony 8	Mean	Colony 9	Mean	Colony 10	Mean	Colony 11	Mean	Colony 12	Mean	Colony 13	Mean	Colony 17	Mean	Colony 18	Mean	Colony 20	Mean	Colony 21	Mean	Colony 22	Mean	Colony 23	Mean	Colony 24	Mean	Colony 27	Mean	Colony 29
0.797616	0.801212	0.630571	0.805402	0.945857	0.871964	2.902323	0.946922	1.342063	0.669581	0.8537	0.748723	1.101245	0.738894	0.636161	0.637341	0.705	0.721006	1.025863	0.90024	1.026495	0.887965	0.822164	0.747867	0.822164	1.088347	0.902841	0.823041	1.838415	0.822905	1.162716	0.779474	0.766458	0.909032	0.71128
0.705	SD	0.630571	SD	0.705	SD	0.603798	SD	0.7114	SD	0.8537	SD	0.630571	SD	0.954533	SD	0.705	SD	1.025419	SD	0.891762	SD	0.822164	SD	1.576428	SD	1.196425	SD	0.902841	SD	0.598212	SD	0.766458	SD	1.14685
0.705	0.253825	1.026495	0.168313	0.822164	0.547498	0.71148	0.468754	0.513209	0.245497	0.911493	0.200604	0.797616	0.116299	0.71156	0.137165	0.85767	0.137484	1.025863	0.224572	0.846	0.175851	0.705	0.1498	0.822164	0.275727	0.581358	0.136722	0.902841	0.257283	1.136778	0.175948	0.830173	0.190487	0.71128
0.705		0.797616		1.41		1.006114		0.766365		0.765808		0.581358		0.636161		0.718962		0.804829		0.945857		0.705		1.016765		0.822164		1.016765		1.136778		0.830173		0.8049
0.718962		0.759308		0.997021		0.725532		0.513209		0.7251		0.598212		0.766773		0.85767		0.804829		0.891762		0.987		1.016765		0.705		1.073824		0.598212		0.8537		1.005859
0.705		0.891762		0.997021		0.603798		0.603728		0.71148		0.598212		0.5865		0.718962		0.910883		1.026495		0.630571		1.026495		0.581358		1.204705		0.630571		0.865774		0.712
0.902841		0.598212		0.705		0.71148		0.603728		0.636117		0.581358		0.7113		0.718962		1.026501		0.846		0.630571		1.337643		0.85767		0.846		0.759308		0.954756		0.954712
0.997021		0.705		0.822164		1.272591		0.636161		0.636161		0.759308		0.7113		0.508383		0.910962		0.891762		0.846				0.846		0.846		0.725405		0.865774		0.636027
0.902841		0.598212		0.581358		0.854		0.450119		0.636117		0.759308		0.766773		0.705		0.899225		0.945857		0.705				0.85767		0.945857		0.630571		0.803713		1.342116
0.718962		0.759308		0.718962		0.71156		0.449802		1.22403		0.705		0.766458		0.508383		1.006072		0.987		0.718962				0.705		0.945857		0.705		1.311735		0.805466
0.822164		0.705		0.822164		0.71128		0.450119		0.830122		0.85767		0.5865		0.705		1.026306		0.822164		0.997021				0.822164		0.902841		1.162716		0.910883		0.636027
0.718962		0.705		1.136778		0.865774		0.910712		0.636161		0.705		0.829264		0.718962		0.910962		1.204705		0.705				0.940475		0.902841		0.759308		0.719736		0.967969
1.269		0.718962		0.581358		0.853		0.449802		0.726061		0.822164		0.71128		0.718962		0.899225		1.196425		0.759308				0.759308		1.128		0.705		0.719736		0.712
1.026495		0.508383		0.85767		0.71156		0.512654		0.603728		0.705		0.636027		0.705		0.725532		0.945857		0.705				0.705		0.718962		0.630571		1.288559		0.865331
0.891762		1.016765		0.718962		0.7114		0.900111		0.954712		0.797616		0.635938		0.846		0.725532		0.822164		0.759308				0.705		0.997021		0.718962		1.147855		0.900142
0.891762		0.718962		0.85767		1.173024		0.900111		0.603728		0.945857		0.635938		0.606871		0.712		1.388689		0.705				0.940475		1.073824		0.85767				0.91104
1.026495		0.705		0.797616		0.586791				0.71148		0.705		0.569		0.822164		1.035836		0.945857		0.705				0.940475		0.797616		0.797616				0.804758
1.128		0.508383		0.718962		0.636475				0.900111		0.718962		0.555744		0.606871		0.712		1.395829		0.759308				0.997021		0.718962		0.630571				0.756227
0.630571		0.891762		0.797616		0.586791				0.71148		0.630571		0.5865		0.718962		1.146924		0.822164		0.598212				0.705		1.162716		0.630571				0.911555
0.705		1.101245		0.797616		1.006171				0.512821		0.705		0.71128		0.564		0.726081		0.822164		0.759308				1.016765		0.797616		0.85767				1.111565
0.797616		1.196425		0.718962		0.636475				0.766736		0.630571		0.383276		0.564		0.82971		0.705		0.718962				0.705		0.846		0.85767				0.865495
0.822164		0.581358		0.902841		1.111079				0.512821		0.725599		0.383276		0.581358		1.0061		0.822164		0.598212				0.705		0.797616		0.979669				0.670979
0.987		0.759308		0.797616		0.865774				1.71926		0.630571		0.636161		0.697561		0.636206		0.997021		0.630571				0.945857		1.128		0.630571				0.603869
0.891762		0.902841		0.797616		0.853				0.587494		0.705		0.5865		0.598212		0.726081		1.067354		0.846				0.705		0.797616		0.987				0.804758
0.997021		0.581358		0.822164		0.513098				0.586548		0.846		0.766773		0.718962		0.829367		0.822164		0.797616				0.85767		1.276809		0.797616				0.769619
0.630571		0.902841		0.797616		0.586524				1.147123		0.725599		0.636161		0.508383		0.636206		0.705		0.797616				0.85767		1.276809		0.797616				1.006114
0.797616		0.846		0.85767		0.71148				0.586548		0.891762		0.804758		0.718962		1.035836		1.212928		0.705				1.016765		0.705		0.630571				0.756227
0.718962		0.718962		0.902841		0.513098				0.829796		0.630571		0.71148		0.718962		0.829367		1.276809		0.630571				0.902841		0.705		1.269				0.830122
0.598212		0.718962		0.718962		1.111079				0.865774		0.846		0.427		0.508383		0.854		0.822164		0.630571				0.822164		1.472083		0.630571				0.569
1.576428		0.997021		0.581358		0.71156				0.765808		0.822164		0.7115		0.705		0.899795		1.067354		0.630571				0.822164		0.705		0.902841				0.573376
0.705		0.987		0.759308		1.173048				0.765845		0.759308		0.7115		0.705		0.829264		0.987		0.630571				0.705		1.838415		0.891762				0.911555
0.797616		0.759308		0.822164		0.899921				0.636117		0.85767		0.71148		0.891762		0.899795		0.987		0.630571				0.705		0.705		0.891762				0.603021
0.705		0.718962		1.212928		1.349818				0.830122		0.718962		0.427		0.508383		0.829264		0.822164		0.759308						0.705		0.705				0.670979
1.073824		0.822164		0.797616		0.586524				0.71128		0.85767		0.603728		0.508383		0.911493		0.705		0.630571						0.945857		0.705				0.573376
0.598212		0.759308		0.705		1.401726				0.711		0.85767		0.954622		0.630571		0.899921		0.902841		1.299956						0.718962		0.705				0.71128
2.096116		0.85767		0.85767		1.485301				1.622171		0.997021		0.766272		1.136778		0.569		0.945857		0.705						0.718962		0.718962				0.766365
0.598212		0.759308		0.581358		0.71128				0.725336		0.759308		0.636161		0.902841		0.569		0.705		0.630571						0.902841		0.718962				0.71156
1.276809		0.822164		0.85767		0.911493				0.636117		0.822164		0.603728		0.668347		0.71156		0.891762		0.718962						0.822164		0.705				0.830122
0.508383		0.846		0.581358		0.71128				0.711		0.718962		0.766272		0.718962		0.865331		0.891762		0.705						0.822164		0.718962				0.7114
1.276809		0.705		0.718962		0.954533				0.910712		0.85767		0.636161		0.668347		0.71156		1.395829		0.705						0.797616		0.650358				0.586524
0.759308		0.797616		0.987		0.82971				0.71128		0.797616		0.5692		0.891762		1.1383		0.718962		1.136778						0.705		0.650358				0.804829
0.598212		0.718962		0.987		0.82971				0.711		0.846		0.5692		0.891762		1.1383		0.718962		0.630571						0.705		0.85767				0.569
0.508383		0.759308		0.822164		1.111002				0.7115		0.822164		0.450309		0.630571		0.712		1.073824		0.759308						0.598212		0.564				0.71128
0.598212		0.508383		0.630571		1.532618				0.636027		0.581358		0.725532		0.630571		0.7251		0.945857		0.705						0.759308		0.718962				0.766365
0.718962		0.759308		0.508383		0.829624				0.766272		0.945857		0.450309		0.718962		0.7251		1.016765		1.128						0.718962		0.630571				0.512654
0.718962		0.508383		1.016765		0.853				0.7113		0.718962		0.636161		0.718962		0.830173		0.705		0.598212						0.705		0.630571				0.742306
0.718962		0.705		0.581358		3.693814				0.7113		0.846		0.804758		0.891762		1.311865		0.705		0.85767						0.508383		0.564				0.765993
0.718962		0.718962		0.891762		0.854				0.91104		0.630571		0.402697		1.136778		0.765882		0.759308		0.598212						0.705		0.630571				0.71128
0.598212		0.987		0.630571		0.765845				0.636564		0.759308		0.402768		0.846		1.272412		0.705		0.508383						0.705		0.718962				0.71156
0.598212		0.762574		0.705		0.82971				0.854		0.581358		0.402697		0.846		1.146986		0.759308		0.508383						0.508383		0.718962				0.766736
0.759308		0.762574		0.797616		0.853				0.636027		0.822164		0.71156		0.508383		0.5865		0.705		0.85767						0.705		0.630571				0.512654
0.708467		0.7755		0.85767		0.854				0.765845		0.630571		0.635938		0.705		0.829796		0.797616		0.822164						0.581358		0.705				0.765993
0.705		0.902841		0.508383		0.765845				0.71208		0.581358		0.449138		0.705		0.5865		0.822164		0.85767						0.759308		0.705				0.804829
0.708467		1.10924		1.128		0.865429				0.636564		0.598212				0.630571		1.401767		0.797616		0.759308						0.581358		0.581358				0.804758
1.026495		0.797616		0.902841		1.083672				0.71148		0.718962				0.508383		0.865758		0.822164		0.85767						0.581358		0.581358				0.513098
0.564		1.10924		0.705		0.865429				0.711		0.846				0.705		1.485397		0.822164		0.718962						0.705		0.822164				0.586548
0.846		0.581358		0.705		0.865429				0.586451		0.564				0.630571		0.725081		0.705		0.508383						0.705		1.498851				0.586524
0.846		0.797616		0.705		1.026251				0.725434		0.759308				0.822164		1.311714		0.822164		0.891762						0.705		0.822164				0.7115
0.581358		0.891762		0.822164		1.035603				0.586451		0.822164				0.797616		0.725081		0.705		0.508383						0.630571		0.846				0.586548
0.508383		0.891762		0.846		1.083633				0.587494		0.598212				0.822164		1.590962		0.822164		0.85767						0.759308		0.85767				0.603728
0.705		0.581358		0.945857		0.636206				0.82971		0.718962				0.630571				0.705		0.508383						0.581358		0.630571				0.513098
0.630571		0.822164		0.705		1.083672				0.865692		0.581358				0.797616				0.891762		1.016765						0.759308		0.822164				0.725728
0.564		0.759308		0.797616		1.622329				0.603728		0.759308				0.630571				0.705		0.718962						0.508383		0.630571				0.765901
0.508383		0.997021		0.85767		1.005718				0.766458		0.705				0.705				0.891762		0.718962						0.705		0.759308				0.766365
0.630571		0.797616		5.337553		0.910883				0.711		0.564				0.987				0.891762		0.902841						0.705		0.759308				0.766458
0.705		1.41		0.705		0.954712				0.603798		0.85767				0.705				0.891762		0.598212						0.630571		0.945857				0.829264
0.846		0.822164		1.196425		0.636206				0.71134		0.705				0.891762				0.997021		0.598212						0.508383		1.016765				0.829264
0.846		0.759308		1.016765		0.636251				0.512321		0.997021				0.705				0.718962		0.822164						0.665361		0.846				0.725434
0.759308		0.891762		0.822164		0.900111				0.603728		0.630571				0.902841				0.997021		0.705						0.649978		0.846				0.854
0.85767		1.026495		0.718962		0.636206				0.829196		0.718962				0.759308				0.630571		0.902841						0.630571		0.822164				0.911493
0.846		1.073824		0.630571		1.591633				0.71096		0.598212				0.997021				0.718962		0.822164						0.705		0.718962				0.586524
1.136778		0.759308		0.846		0.725532				0.603021		0.705				0.581358				0.630571		0.718962						0.64949		1.016765				0.603728
0.705		0.822164		0.846		0.829367				0.603798		0.705				0.718962				0.822164		1.016765						0.997021		0.759308				0.765901
0.508383		0.997021		0.705		0.954443				0.603869		0.630571				0.630571				1.073824		0.846						0.630571		0.718962				0.766365
0.630571		0.822164		0.945857		0.725532				0.804758		0.705				0.718962				0.705		0.697561						0.649978		0.705				0.603021