PCAS 21 (2018/2019)

Supervised Project Report
(ANTA604)

Population Dynamics of Three Emperor Penguin Colonies in the Ross Sea

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Word count: 5100 (excluding abstract, references and appendix)

Abstract

Emperor penguins were found to be breeding in the Ross Sea region in Antarctica in 1902 and since then there has been monitoring of the 7 Ross Sea colonies, but this has been quite inconsistent. This paper provides data on chick and adult counts from 2018 on three Ross Sea emperor penguin colonies; this is the first time since 2012 that these colonies have been visited and counted. We took aerial photos of three Ross Sea colonies; Cape Crozier, Beaufort Island and Franklin Island. Then from these images I counted all the chicks on a total of 10 images for the three colonies. I counted 1,365 chicks at Cape Crozier, 417 chicks at Beaufort Island and 2,372 chicks at Franklin Island. I then compared the chick counts to the concurrent adult counts at the same colonies, conducted regression analysis and made comparisons. We found that all three colonies exhibit very different population dynamics over time. While the adult counts are somewhat similar for the Cape Crozier and Beaufort Island colonies, the chick counts show no similarity across the three colonies. Cape Crozier is the colony that exhibits a strong trend in terms of the relationship between the number of chicks and adults each year, and this past 2018 season had the greatest yield of chicks ever recorded at this colony. We present in the findings of this paper that extrapolating patterns of population dynamics between colonies in the Ross Sea is not appropriate as there is no pattern or trend that is similar between the three colonies. Therefore, future research and monitoring of these colonies needs to be consistent in order to be able to detect changes at each of the individual colonies. With the threat of climate change looming, the habitat and ultimately the fate of the emperor penguin species is at risk. There are huge benefits in future monitoring; to determine both negative effects of climate change and positive effects of marine protected areas. There is the potential to use this species as an ecosystem sentinel to inform on the health of not only the Ross Sea region but potentially the Southern Ocean.

Introduction

Emperor penguins (*Aptenodytes forsteri*) were first discovered to be breeding in the Ross Sea by a member of Scott's expedition party in 1902 (Stonehouse, 1964; Kooyman & Ponganis, 2017). Since then there have been a total of seven colonies identified in the Ross Sea and this region is known to have the largest concentration of emperor penguins in Antarctica (LaRue et al., 2015; Kooyman & Ponganis, 2017). Population counts have been conducted intermittently since 1902, with a very comprehensive record of the number of chicks and adults recorded at most of the Ross Sea colonies during a period from 2000 to 2012 (Stonehouse, 1964; Kooyman et al., 2017).

Emperor penguins have been previously determined to be an appropriate species to study via remote sensing technologies (Fretwell et al., 2012). This species meets the main remote sensing criteria posed by LaRue et al. (2016) that makes it possible to measure population dynamics of certain wildlife species. These criteria include: an open landscape, sufficient size of the organisms or its proxy, and the organism contrasting with its landscape (LaRue et al., 2016). As a species, emperor penguins meet all of these criteria as they live in a polar region where there is minimal landscape features and they breed at predictable sites on sea ice where they contrast with their environment (Fretwell et al., 2012). Therefore, emperor penguins have been studied in recent years via remote sensing technologies such as aerial photography and very high-resolution imagery (VHR) (Fretwell et al., 2012; Kooyman & Ponganis, 2017). In fact, a new colony that was not previously known about has even been discovered via VHR and the existence of this colony was confirmed in 2013 (LaRue et al., 2015).

Previous years of data obtained from published literature has shown great variability in the adult and chick numbers of emperor penguin colonies in the Ross Sea (Stonehouse, 1964; Kooyman et al., 2007; Kooyman & Ponganis, 2017). This variability occurs in successive years in certain colonies, some of this is known to be caused by environmental factors but some of the variability is unexplained (Kooyman et al., 2007; Kooyman & Ponganis, 2017). An example of an environmental factor is from Cape Crozier where an iceberg impacted the survival of chicks and the numbers of chick decreased from 1,201 in 2000 down to zero in 2001 (Kooyman et al., 2007; Kooyman & Ponganis, 2017). While some unexplained variation in population numbers occurred at Franklin Island where numbers of adults and chicks almost halved from 2006 to 2007 (Kooyman & Ponganis, 2017). Kooyman & Ponganis (2017) propose multiple reasons as to why these fluctuations in colony populations numbers of both adults and chicks is occurring. These reasons include breeding behaviour of the species and also environmental influences (Kooyman & Ponganis, 2017). Therefore, there is a need to continue the monitoring of emperor penguins in the Ross Sea region.

Fretwell et al. (2012) indicated the importance of knowing the populations dynamics and the causes of these in the emperor penguin populations. Climate change is a major factor that is likely to affect the colonies of emperor penguins in Antarctica. Since this species breeds on the sea ice, a warmer climate could cause a decrease in sea ice and negatively affect the survival and breeding success of the penguins (Fretwell et al., 2014). A paper by Jenouvrier et al. (2014) used models and they predicted that more than two thirds of the existing emperor penguin colonies are likely to have declined by more than 50% of their current population by the year 2100. However, we cannot understand the full extent of the impacts of climate change without knowing the current status of the penguin colonies. Emperor penguins are also indicators of ecosystem health in the Southern Ocean and so it is very important to be able to know the 'normal' population dynamics for emperor penguins in order to be able discriminate the unusual dynamics (LaRue et al., 2015). Therefore, leading to the need for continued monitoring of this species in the Ross Sea region.

We took aerial photos of Ross Sea emperor penguin colonies during October and November of 2018. The data obtained from these images will provide crucial insight to the penguin colonies status and if it has changed in recent years. There has been a five year period (from 2013–2017) where there was no data collected on the emperor penguin colonies in the Ross Sea region. So, the aim of this 2018 data is to restart monitoring in order to inform on the potentially changing population dynamics of the emperor penguins. More information on the emperor penguins in the Ross Sea region can provide crucial information on the impacts of climate change and the recently instated Ross Sea region Marine Protected Area (MPA).

Methods

Aerial photographs were taken via helicopter flights during October and November 2018 of Ross Sea emperor penguin colonies. Researchers flew at an altitude no lower than 500m at oblique angles to the colonies. All images were captured under ACA #2019-006. In total 6 flights were made over a period of 31 days and monitoring 3 individual colonies (Table 1).

DATE	COLONY	NUMBER OF IMAGES COUNTED
13/10/2018	Beaufort Island	1
25/10/2018	Cape Crozier	3
29/10/2018	Cape Crozier	1
31/10/2018	Franklin Island	1
9/11/2018	Cape Crozier	3
13/11/2018	Cape Crozier	1

Table 1 – number of images and dates images were taken of each colony

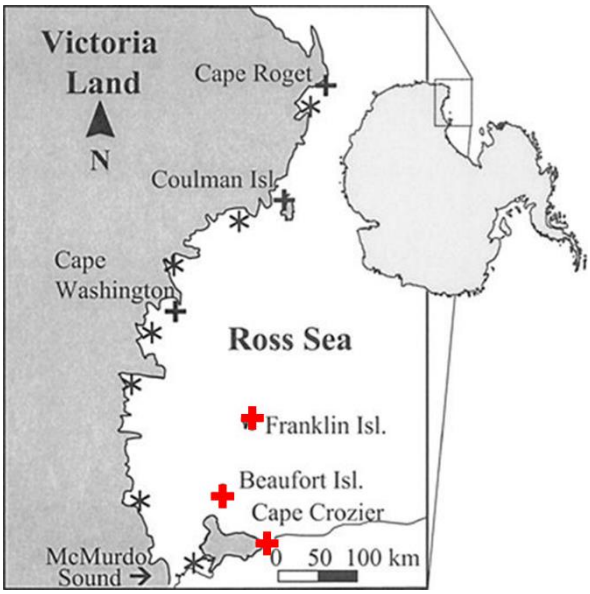

Figure 1 – Map of the emperor penguin colonies in the Ross Sea region. The three colonies I counted are marked by red crosses. Adapted from: Burns & Kooyman (2001), Habitat Use by Weddell Seals and Emperor Penguins Foraging in the Ross Sea, Antarctica.

We stitched the images together in Adobe Photoshop and then analysed them in ImageJ (ImageJ, 2018). The images analysed were of 3 colonies in the Ross Sea; Cape Crozier, Beaufort Island and Franklin Island (Figure 1). We counted eight images for the Cape Crozier colony whereas we only counted one image for both the Franklin Island and Beaufort Island colonies. Cape Crozier was visited 4 times and so there were more images taken of this colony than the other two colonies which were only visited once each (Table 1).

In each image I marked all the emperor penguin chicks that could be seen and then ImageJ (ImageJ, 2018) totalled how many chicks I had counted in each image. Figure 2 shows an example of what marking the chicks looked like on an image being analysed in ImageJ.

Figure 2 – screenshot from ImageJ while marking and counting chicks in an image, each penguin chick was marked with a yellow cross

We then collated all the data into an Excel spreadsheet. There were two counters for some of the images to account for error and to ensure consistency of the method of counting. Overall the counts are best estimates for the number of penguin chicks at the colonies at that point in time.

Once we had counted all the chicks, we combined the data with longstanding time series of chick data from the same colonies in the Ross Sea as published by multiple authors; Stonehouse (1964), Kooyman et al. (2007), Barber-Meyer et al. (2008) and Kooyman & Ponganis (2017). This allowed us to compare chick numbers within and among colonies across multiple years.

We also obtained the adult counts for the same images for which we had counted chicks, in order to conduct some comparisons. We used the ratios of adults to chicks to form regression graphs where we could test how strong the relationship is between the number of chicks and adults at each colony. From these graphs we were also able to predict the number of adults from a known number of chicks for Franklin Island where the data for the adults is not yet available. We did this by using the equation for the relationship between the two variables (number of adults and number of chicks).

We then constructed time series graphs to show any patterns within the number of chicks or adults over time at each of the colonies. We specifically compared Cape Crozier and Beaufort Island colonies as they are relatively similar in size and closely located to each other. We were able to see if the trends or patterns seen in closely related colonies were similar or different to each other in terms of chicks and adult numbers each year.

Results

A table of the raw data of the chick counts from each of the images can be found at Appendix 1.

Table 2 shows the number of chicks that were counted in each image on each date at each colony. Since there were multiple images over multiple dates for the Cape Crozier colony, all the chicks from all the dates were averaged and this is the number (1,365 chicks) we used for the number of chicks recorded at this colony for the 2018 season (Table 3). After counting we noticed that image 1 from the 9/11/2018 flight over the Cape Crozier colony had significant overlap with image 2 and so image 1 was not used in any of the calculation or analysis. The number of chicks recorded for Franklin Island is a minimum number as there were 6 small patches on the image where the quality was too bad to allow for counting to be conducted.

DATE	COLONY	IMAGE	NUMBER OF CHICKS
13/10/2018	Beaufort Island	1	417
25/10/2018	Cape Crozier	1	0
25/10/2018	Cape Crozier	2	791
25/10/2018	Cape Crozier	3	536
29/10/2018	Cape Crozier	1	1318
31/10/2018	Franklin Island	1	2372
9/11/2018	Cape Crozier	1	1011
9/11/2018	Cape Crozier	2	1039
9/11/2018	Cape Crozier	3	596
13/11/2018	Cape Crozier	1	1306

Table 2 – number of chicks counted in each image for each colony

Table 3 shows the final number of chick and adult emperor penguins counted at each of the three colonies for the 2018 season.

Colony	Chicks	Adults
Cape Crozier	1365	1665
Beaufort	417	462
Franklin	2372	N/A

Table 3 - total number of chicks and adults counted at the three colonies for the 2018 season

The counts for the emperor penguin chicks and adults are both reliable as both have had multiple people counting them. For the adult counts there were usually four counters and then the average number of adults was used. For Cape Crozier, two people counted two of the images and both the counts were close to each other (Table 4). The difference in chicks counted ranged from 52-206 chicks which is less than 10% of the average number of chicks counted for those images. Counter 2 was consistently counting less chicks per image which also strengthens the reliability of the counts.

	Image 1	Image 2
Counter 1	1327	1635
Counter 2	1121	1583
Difference	206	52

Table 4 - results of two counters counting chicks in two of the same images

Figure 3 shows the ratios of adult to chick numbers for each of the three colonies. There is a strong association between the number of chicks and the number of adults at Cape Crozier (Figure 3, a) where the R^2 value is 0.80 (2 dp). The trend for this colony being as the number of adults increases so does the number of chicks.

However, there is a much weaker relationship between the same two variables at Beaufort Island and Franklin Island colonies (Figure 2, b & c) where the R^2 values are 0.13 (2 dp) and 0.25 (2 dp) respectively. The number of adults seems to stay relatively stable over a large range of chick numbers. This is more so for the Beaufort Island colony than the Franklin Island colony where the relationship is slightly stronger, and we see more of an increase in chicks with an increase in adults.

Since the Franklin Island adults have not yet been counted I used the equation in Figure 3, c) to predict the number of adults we expect to count in this image.

Number of adults = (0.3679*number of chicks) + 2738.2
= (0.3679*2372) +2738.2
=3610.859

So, the number of adult penguins we expect to count in the Franklin Island image is 3611 penguins (nearest whole number).

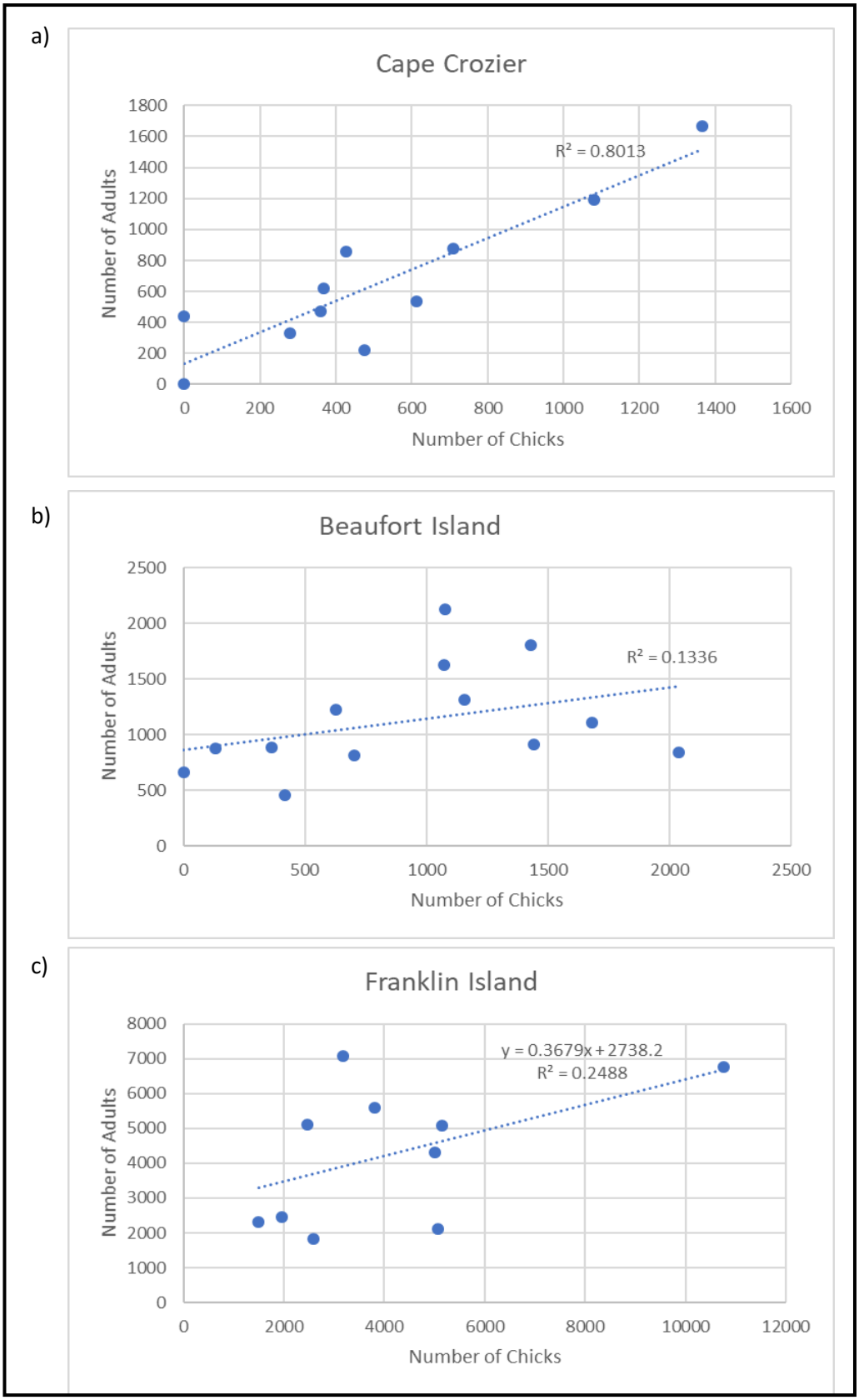

Figure 3 – Regression graphs showing the relationship between the number of chicks and the number of adults at a) Cape Crozier, b) Beaufort Island and c) Franklin Island. These were constructed based on all years where both chick and adult counts were available.

Cape Crozier has data available on chick numbers from 1902, so I combined the new data from 2018 to make a time series over a period greater than a century (Figure 4). While the data is inconsistent over the past years we can see from the time series that the colony has varied greatly in the number of emperor penguin chicks each year. The lowest recorded number of chicks was in 1902, 2001 and 2005 when there were zero living chicks being recorded in the observations. The year that showed the greatest yield of emperor penguin chicks was 2018 with 1,365 chicks being counted. The last time the number of chicks was almost this high was in 1961.

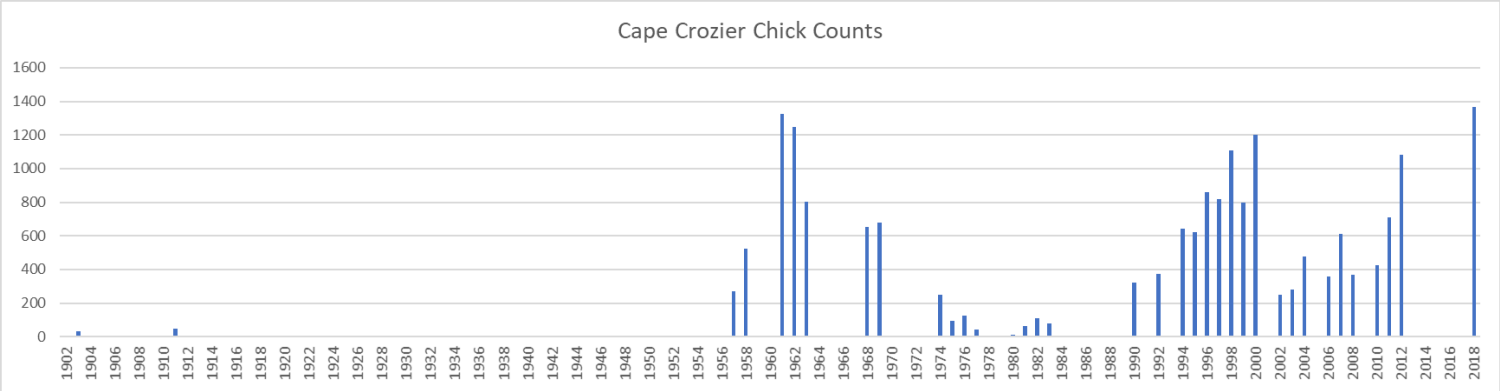

Figure 4 – Time series graph showing the numbers of emperor penguin chicks recorded at the Cape Crozier colony from 1902-2018. Note that in 1902, 2001 and 2005 there were actually zero chicks recorded at the colony. All other years without data are years where there is no data available because there was no evaluation completed that year.

Beaufort Island and Franklin Island colonies also show large amounts of variation in the number of chicks recorded each year (Figure 5). Figure 5 shows the period of most consistent data for these colonies as data from further back than 1994 is highly inconsistent. The range over which the number of chicks can vary is significant also. For Franklin Island, in 2005 there were around 2,000 chicks recorded but then the next year there were over 10,000 chicks recorded.

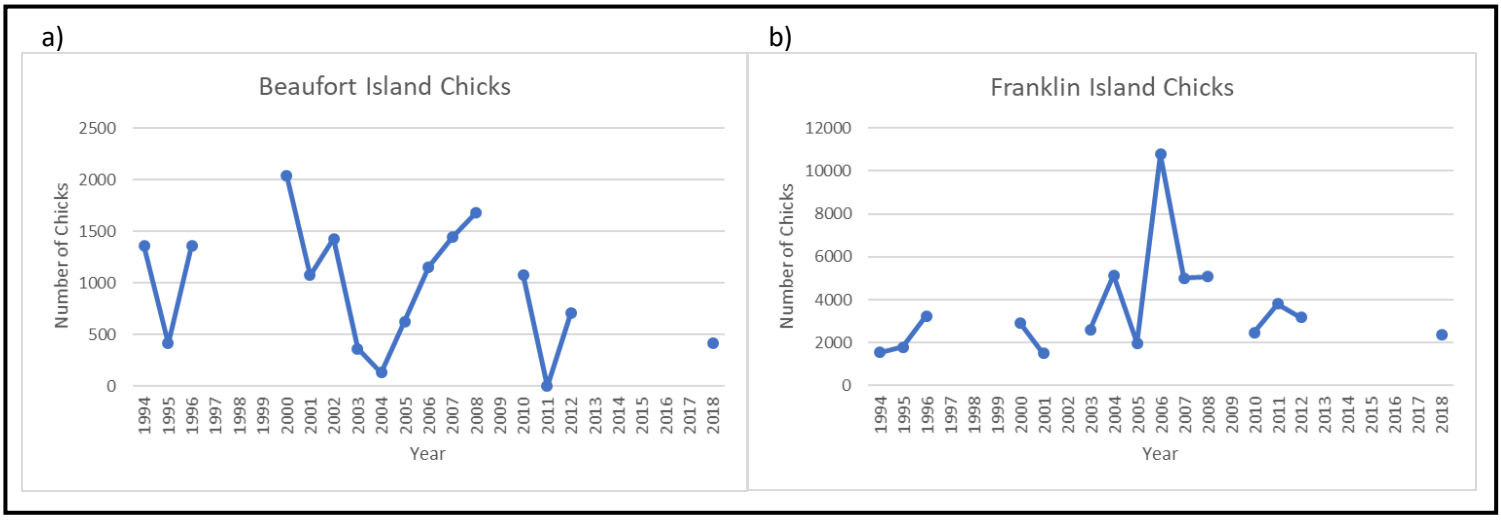

Figure 5 – counts of emperor penguin chicks since 1994 to present at a) Beaufort Island and b) Franklin Island

The variation in the number of penguin chicks recorded at each colony is not only across multiple years but there is also huge variation in successive years too. While all the colonies show variation in the number of chicks each year, the variation is not the same for all three colonies. Figure 6, a) shows that the rise and fall in chick number is not the same pattern for the closely located colonies of Cape Crozier and Beaufort Island.

However, Figure 6, b) shows that the adult counts for these same two colonies are much more stable compared to the chick numbers. They almost show some degree of synchronisation where they follow a similar pattern of rise and fall in the 21st century, especially within the period of 2003-2008, with a couple of exceptions. It is also interesting to note that for Cape Crozier the number of adults also reached a record high in 2018, like with the number of chicks.

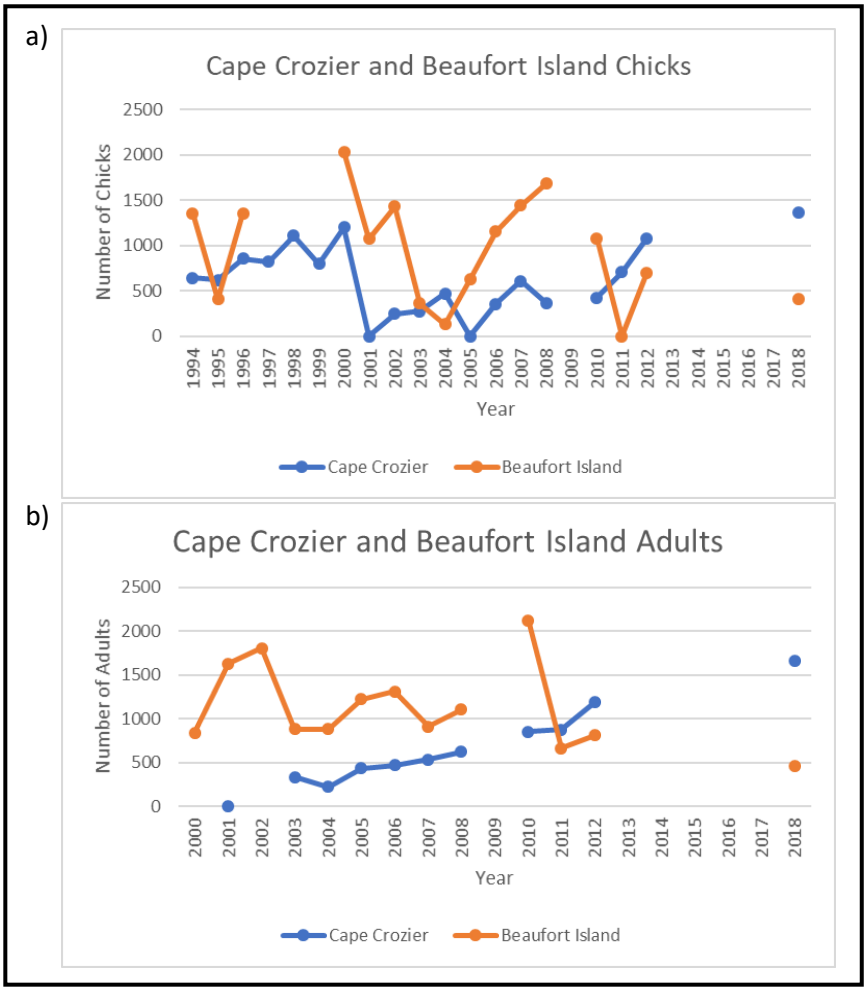

Figure 6 – Cape Crozier and Beaufort Island counts of a) chicks since 1994 and b) adults since 2000.

Both the adult and chick numbers show the effects of localised environmental events. In 2001, an iceberg (B15A) destroyed the nesting area at Cape Crozier (Kooyman et al., 2007) and we can see the effects of this in Figure 6 as both the adult and chick numbers were reduced to zero that year. The same iceberg affected the Beaufort Island colony in 2002-2004. During this period the iceberg had travelled northwards and formed a barrier preventing the adults returning to the Beaufort Island colony area (Kooyman et al., 2007). So, we see a decrease in both the chick and adult numbers during this period.

Discussion

This study is the first since 2012 to address emperor penguin population trends in the Ross Sea and found not only record chick counts at Cape Crozier but also discrepancies in the ratios between chick and adult counts over time at these colonies. My work suggests that emperor penguin population dynamics are highly variable and that environmental impacts have the possibility to threaten the existence of some of these colonies.

Chick counts at these colonies are essentially a proxy for hatching success and breeding success of the colony. Where the images were high quality the accuracy of the chick counts can be high, but the

accuracy declines with decreasing image quality. Therefore, it is possible that we missed a number of chicks as they may have been situated behind adults or in creche's and so preventing us from seeing them in the two-dimensional images. This is where ground counts could help to confirm chick numbers when the likelihood of missing some chicks is high.

We can see from Table 3 that the number of chicks at both Cape Crozier and Beaufort Island are relatively close to the count for the adults for 2018. However, since it takes a breeding pair of adult emperor penguins to hatch a chick we would expect that the number of adults would be at least double that of the number of chicks. Therefore, I would suggest that many adults are missing in the images taken as adults are mobile and often out foraging (Kooyman & Ponganis, 2017). According to Kooyman & Ponganis (2017) in late October there is usually only one parent with the chick, on occasion there may be both parents. The images we counted for the 2018 season were taken during late October and early November. Therefore, the number of adults counted at these colonies are likely to be more representative of the number of breeding pairs rather than the absolute number of adult penguins in the colony.

It is important to know the number of chicks in a colony of emperor penguins as they can tell us the minimum number of breeding pairs that were present in the colony. It is a minimum count as there will be many chicks that do not survive but they still would have accounted for a breeding pair in the colony for that year. By comparing the chick counts (hatching success) to the adult counts (number of breeding pairs) we can also get an estimate of the number of chicks that did not survive for that season. Chicks are not mobile like their parents before they moult and so from an image they are more likely to be the most accurate absolute count. This is compared to the adults where an absolute count of adults in a colony would be very difficult as many of them go out foraging and so not all the adults will be present at one time (Kooyman & Ponganis, 2017). Therefore, an accurate count of the number of surviving chicks in a colony can provide us with an estimate for the minimum size of the colony that year, which is helpful when trying to analyse population dynamics of this species.

The correlation between the number of chicks and the number of adults is very different among the three colonies. Cape Crozier has the strongest relationship ($R^2 = 0.80$) followed by Franklin Island ($R^2 = 0.25$) and then Beaufort Island ($R^2 = 0.13$) (Figure 3). The strong relationship between the variables at Cape Crozier suggests that the breeding success of the colony is very good each year as almost each breeding pair seems to have successfully raised a chick. However, Beaufort Island showed a very different trend where the number of adults seemed to be relatively stable over a large range of chick numbers. This suggests that the Beaufort Island colony has very variable breeding success each year and that some years there are many breeding pairs but very few chicks successfully hatched. Franklin Island lies somewhere between Beaufort Island and Cape Crozier in terms of its breeding success.

However, a variable number of adults could also mean that there are a lot of non-breeding adults in the colony. If there is a year when the number of adults is much higher than the number of chicks then this may be an indication of non-breeders being present in the colony. For example, at Franklin Island there was a year when there were about 7,000 adults but only 3,000 chicks, the explanation for this could be that the colony had many non-breeding adults present that year. Therefore, based on the regression graphs, we can suggest that there are more non-breeding adults present at the Beaufort Island and Franklin Island colonies than at the Cape Crozier colony. This could possibly be due to location as Cape Crozier is the southern-most colony in the Ross Sea and so it may be too far for non-breeders to want to go. So, Cape Crozier is more likely only inhabited by breeding adults.

These results have implications and limitations for when interpreting satellite images of the colonies. From satellite images you can only count adult penguins and not the chicks. The information we can get from satellite imagery on the Beaufort Island and Franklin Island colonies is limited compared to the amount of information we can get for the Cape Crozier colony. By knowing that Cape Crozier has a strong relationship between the number of adults and chicks each year, a reasonably good prediction can be made about the breeding success of the colony from a satellite image. However, this prediction is less reliable with the same type of images from the Beaufort Island and Franklin Island colonies as there is much more variability in the relationship between chick and adult numbers, and possibly many more non-breeders at these colonies. Therefore, using satellite imagery is not going to give reliable information about the breeding success of these colonies as the number of adults counted may not represent the number of truly breeding adults.

It is not safe to assume that we can extrapolate what we see at the most stable colony, Cape Crozier, and apply the same population patterns to the other close by colonies in the Ross Sea region. For example, at Cape Crozier if there is a year where the number of chicks is significantly less than the number of adults then we could confirm that this is an unusual year for this particular colony and effort could be made to investigate why this is. However, the same cannot be said for Beaufort Island where there is no real relationship between the number of adults and chicks, so there is less certainty when looking at this colony in being able to identify years of unusual dynamics. Therefore, we have learned that Cape Crozier is the best colony to study in terms of identifying years where the colony has been impacted in terms of their breeding success in some way. This is because the relationship between the number of adults and chicks is usually quite strong, so any deviation can be readily identified. However, the difference in the correlation between the chick versus adult counts among the three colonies suggests that these colonies are dynamically acting very differently from each other. Obviously, these colonies are highly influenced by localised events that have effects specific to only one colony.

As we have seen from the time series graphs with the 2018 counts included, there is great variability in the number of penguins chicks each year at each colony. This variability is greater in the chicks more so than the adults. This suggests that the hatching success is a lot more sensitive to environmental effects where as adult penguins are more resilient and adaptive (Barbraud & Weimerskirch, 2001). Kooyman & Ponganis (2017) made suggestions as to possible reasons for this variation, including environmental events and breeding behaviour of the species. Two suggestions stand out as possible explanations for the variation we see in the Ross Sea colonies particularly. Firstly, emperor penguins are known to have low mate and site fidelity which leads to the ability for emigration of individuals. Emigration in emperor penguins has been recently suggested by LaRue et al. (2015) and it has been proposed that some of the rise and fall in penguin numbers in the Ross Sea colonies could be due to emigration and immigration of individuals (Kooyman & Ponganis, 2017). LaRue et al. (2015) also state that the life history of this species is plastic and aids them in surviving climate change effects. This means that with climate change effects looming the adult emperor penguins will likely have some potential to adapt and hopefully find better colony locations for the breeding season. Such climate effects that could negatively impact the survival of the penguins include a decrease in sea ice which acts as an optimal breeding substrate and then consequently less primary production and food for the adults (Kooyman & Ponganis, 2017). Fretwell et al. (2014) have discovered colonies of emperor penguins that are living on ice shelves rather than the sea ice which was assumed to be the only type of area that they would breed on. So, there is hope that the emperor penguins do possess some adaptive capabilities in order to buttress the effects of climate change. The second reason for variation is that the adults will skip breeding for that year if the pre-breeding foraging or sea ice conditions are inadequate for successful breeding (Kooyman &

Ponganis, 2017). Emperor penguins are quite long lived and so they are able to sustain this strategy as they have many years in which they have breeding opportunities. However, with sea ice expected to decrease with climate change, the possibility of adults skipping breeding seasons more frequently is a huge concern (Arrigo & Thomas, 2004; Turner et al., 2016; Turner et al., 2017). We would expect to see that when there is a season of adequate sea ice there would be an increase in the colony size and hatching success compared to years where sea ice is inadequate.

Past data indicates that the impact of localised environmental events can have huge consequences especially on hatching success but also on the adult numbers. We saw this with the B15A iceberg impacting both the Cape Crozier and Beaufort Island colonies separately (Kooyman et al., 2007). These colonies are less than 100km apart from each other, but we have seen that the effects at even closely located colonies can be dramatically different. Therefore, we cannot assume that patterns of breeding success we observe in one colony will be the same at any other colony even in the same region. However, Cape Crozier seems to be the most consistent in terms of the hatching success compared to the number of adults each year and so this may suggest that this colony is located in an optimal area. Cape Crozier is the southernmost colony in the Ross Sea region and this may be a factor that lends to the success of this particular colony.

Adult numbers at the Cape Crozier and Beaufort Island colonies follow a similar pattern of rise and fall in numbers over multiple years. This suggests that adult emperor penguins are being affected by more broad events like Southern Ocean productivity and sea ice formation rather than localised events. While the hatching success is fundamental for recruitment success each year, this is affected more by stochastic events. Since the number of chicks at Cape Crozier was recorded as the highest it has ever been this indicates that the environmental conditions in this area during 2018 must have been optimal for breeding. However, the adults are more likely to suffer from climate change effects that are more global and large-scale events. You cannot even get hatching success without having adults arriving at colonies to physically lay eggs, so concern should be over the future health of the Southern Ocean. If the Southern Ocean fails to provide optimal conditions (sea ice and productivity), then the fate of the emperor penguins along with most other Southern Ocean species will be at huge risk. Some evidence of adult penguins adapting to some climate change effects that are already occurring is at Cape Crozier. For the 2018 season both the chick and adult numbers at Cape Crozier were the highest ever recorded in the 21st century. This may be evidence of emigration of adults southward towards the Cape Crozier colony as climate change starts to alter the environment further north. However, there is no colony further south in the Ross Sea, so if immigration into Cape Crozier continues to occur this colony could be expected to increase dramatically in size in the future.

There is a strong need to continue monitoring at all 7 Ross Sea colonies as the possibility of emigration and localised effects are now known and under the right circumstances we would expect movement to occur between colonies. It is inappropriate to look at one colony and extrapolate the patterns across regions or continent-wide, even though these colonies are relatively closely located to each other in the Ross Sea. With climate change looming and threatening the Ross Sea region with dramatic environmental changes, especially to the sea ice, it is imperative that we know what the 'normal' population dynamics of the emperor penguins are. Without knowing a baseline level we cannot identify unusual changes to the populations of the penguins in this region (Younger et al., 2017). Therefore, not only is continued monitoring needed but consistent monitoring is essential to learning more about the population dynamics of the emperor penguins in the Ross Sea region. The benefits will not only be to identify negative effects of climate change, but this will also hopefully be able to identify some positive effects of a functioning MPA region in the Ross Sea. The findings in this

study also help to better interpret satellite imagery of these colonies and the behavioural ecology of the emperor penguins in the Ross Sea region.

Emperor penguins are not necessarily under threat now, but they could be very soon. The International Union for the Conservation of Nature (IUCN) Red List status for emperor penguins (*Aptenodytes forsteri*) has only recently been upgraded to 'near threatened' from 'least concern' in 2012 (IUCN, 2019). However, a paper published by Jenouvrier et al. (2014) highlights the massive declines in emperor penguins they expect to see as modelled by climate models. They predicted that by the year 2100 all emperor penguin populations will be declining and "at least two thirds [of the emperor penguin populations] are projected to have declined by >50%" (Jenouvrier et al., 2014). This makes it imperative that we need to do everything we can to understand these populations now, so we can help to conserve this endemic species in the future.

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Appendix 1

COLONY				
Beaufort (31/10/18)			MEAN	STDEV
Charlotte	417		417	0
Franklin (31/10/2018)			MEAN	STDEV
Charlotte	2372		2372	0
Cape Crozier (25/10/18)			MEAN	STDEV
Charlotte	1327		1224	103
Michelle	1121			
Cape Crozier (29/10/18)			MEAN	STDEV
Charlotte	1318		1318	0
Cape Crozier (9/11/18)			MEAN	STDEV
Charlotte	1635		1609	26
Michelle	1583			
Cape Crozier (13/11/18)			MEAN	STDEV
Charlotte	1306		1306	0
Cape Crozier Average			MEAN	STDEV
	1224		1364.25	145.8636
	1318			
	1609			
	1306			

Appendix 1 – table showing all the counts of the images across the three Ross Sea emperor penguin colonies. The mean number of chicks was calculated when there was more than one counter. Also, the standard deviation was calculated. Multiple images were taken at Cape Crozier so these were averaged and named "Cape Crozier Average".