The New Zealand King Salmon Company Ltd

Richmond and Waitata Marine Farms

King Shag Management Plan

11 June 2015

Prepared for	The New Zealand King Salmon Co. Limited
Plan prepared by	Rob Schuckard
Reviewed by	▪ Mark Gillard & Karen Mant (King Salmon) ▪ Graeme Taylor and Andrew Baxter (Department of Conservation) ▪ Tangata Whenua Panel • Ngāti Kōata Trust • Te Runanga o Ngāti Kuia Charitable Trust

Figure 1 – New Zealand King Shag

Contents

1 Introduction

New Zealand King Salmon (NZKS) currently has five salmon farms (eight sites) in the Marlborough Sounds; located at Ruakaka Bay, Forsyth Bay, Waihinau Bay, Otanerau Bay, Te Pangu Bay, Clay Point, and two at Crail Bay. Resource consents for three new farm sites were granted in April 2014 and the following farms will be established in due course: Waitata, Richmond and Ngamahau.

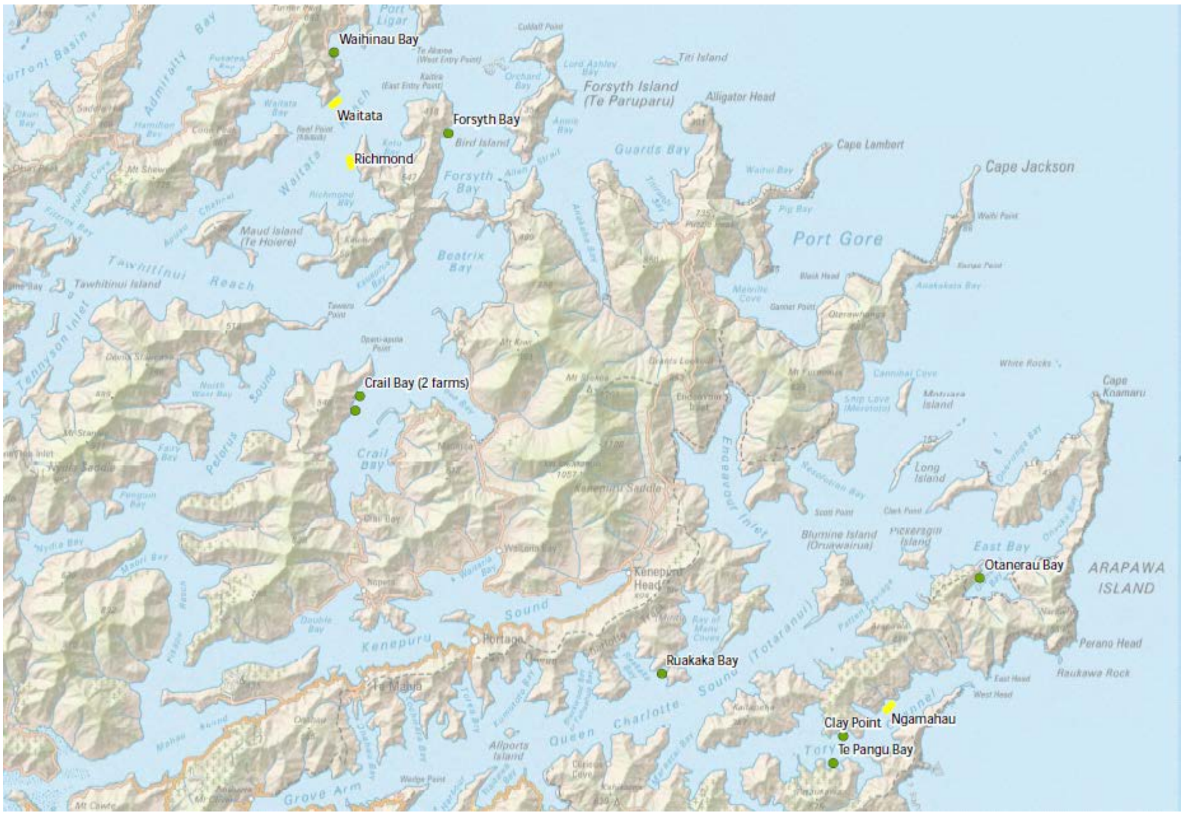

Figure 2 – NZ King Salmon farm sites

During the recent Board of Inquiry process a number of concerns were raised regarding the effect of salmon farming on New Zealand King Shag *(Leucocarbo carunculatus).* The Board decided that a King Shag Management Plan (KSMP)[1] for farms in the Waitata Reach would be required to ensure the establishment and operation of the marine farm does not result in a reduction in the population of King Shag in the Marlborough Sounds, with particular regard to the Duffers Reef Shag colony.

2 Consultation

This KSMP has been developed in consultation with the Tangata Whenua Panel, Ngāti Kōata Trust Te Runanga o and Ngāti Kuia Charitable Trust, and the Department of Conservation

The 'King Shag Population Modelling and Monitoring' report by Darryl I MacKenzie, 10 September 2014 Appendix 1 has been used as a reference in the preparation of this Management Plan.

[1] Decision Document – Appendix 9 – 13 March 2013 – Condition 10 & 11 http://www.marlborough.govt.nz/Services/Property-File-Search.aspx

Decision Document - Appendix 10 – 13 March 2013 – Condition 10 & 11 http://www.marlborough.govt.nz/Services/Property-File-Search.aspx

3 Distribution and Abundance

The New Zealand King Shag (King Shag) is one of the rarest seabirds in the world and is endemic to the Marlborough Sounds.

Low numbers and a very small distribution area are a continuous concern for the survival of this species.

Historically, the average total population of King Shags was estimated to be 645 birds[2]. That figure was based on the average estimated number of shags between 1992 and 2002. About 92% of all the birds were at four discrete colonies; Duffers Reef, Trio Islands, Sentinel Rock, and White Rocks. During this same period about 102-126 breeding pairs were identified each year, with an estimated annual recruitment of 40-68 birds.

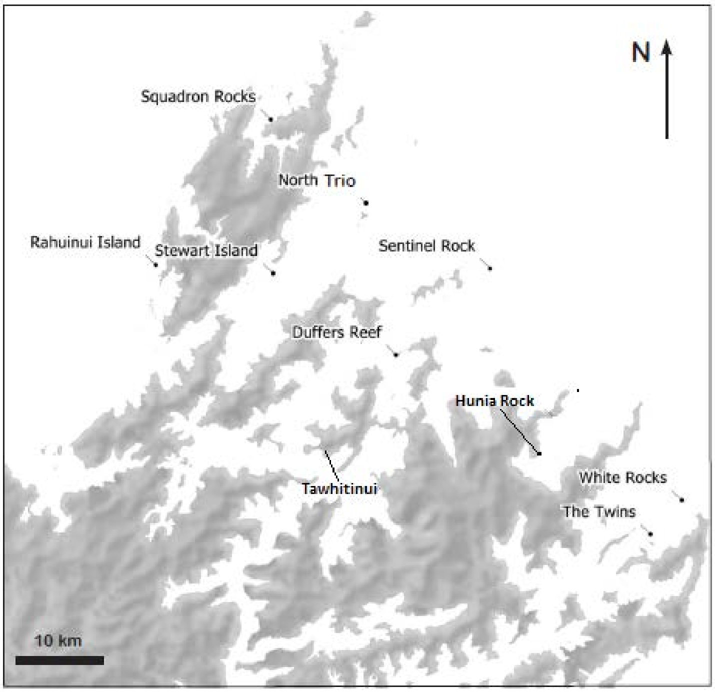

Figure 3– Map of King Shag colonies

King Shag colony counts made between 1992 and 2002 were similar to other counts made over the past 50-100 years, suggesting numbers have been relatively stable for a long time. This indicates a long-term balance between recruitment and mortality in this species.

Historical data on King Shag numbers have been supplied by Mr Rob Schuckard and analyzed by Mr Darryl MacKenzie of Proteus Wildlife Research Consultants Appendix 1.

Modelling King Shag numbers from 1994-2002 was carried out for the purpose of designing a monitoring program to establish what potential change in bird numbers could be regarded as a potential “effect” from the salmon farm activity.

Analyses of colony counts for the King Shag suggest the population has been relatively stable from 1994-2002. A 4-stage population model is used (chicks, year 1 birds, year 2 birds and adults) and the stable age distribution determined for a range of demographic parameter values. By comparing the results of the population model to collected count data, it would be reasonable to expect annual adult mortality for King Shags to be between 0.10 - 0.15, which is similar to that estimated for other shag species.

The criteria of the International Union for Conservation of Nature and Natural Resources (IUCN) for threatened species has identified the King Shag with 32 other New Zealand Birds as “VULNERABLE”, where this “species is facing a high risk of extinction in the wild in the medium-term future”. The status of this bird is based on the latest IUCN criteria:

[2] Schuckard, R. 2006. Population status of the New Zealand King Shag (*Leucocarbo carunculatus*). Notornis Vol 53: 297-307.

1. Area of occupancy estimated to be less than 2000 km^2.
2. They are known to exist at no more than 10 localities.
3. Population estimated to number less than 1000 mature individuals.

In the New Zealand threat classification assessment, the King Shag has the second highest threatened status: "NATIONALLY ENDANGERED[3]". This assessment is based on its small population of between 250-1000 individuals.

Red List IUCN	NZ threat classification	
Least Concern	Not Threatened	
Near Threatened	At Risk	• Naturally Uncommon • Relict • Recovering • Declining
Vulnerable Endangered Critically Endangered Extinct in the Wild	Threatened	• Nationally Vulnerable • Nationally Endangered • Nationally Critical
Extinct	Extinct	

Table 1 - New Zealand Threat Classification System compared with IUCN Red List.

Assessments for King Shag are highlighted red for both classifications

Duffers Reef and the Trio Islands previously had the highest numbers of King Shags of all colonies. Duffers Reef also has also the highest recruitment of all colonies.

It has been observed that when birds depart from the Duffers Reef Colony, 10-60% fly in a west and southwest direction into Waitata Reach. Approximately 8-35% of all the departing birds fly to Forsyth Bay and Beatrix Bay; 82% of all the birds in Forsyth Bay and Beatrix Bay are recorded within 12km from the Duffers Reef colony, feeding predominantly in water depth of between 20-40m. Of all recorded feeding King Shag observations (about 1000) in the Pelorus Sound and the Queen Charlotte Sounds about 80% of all the observations are within 15km of the colonies where most are between 5 and 12 km from the rocks where they are breeding.

4 Buffer Area

There is potential for King Shags to be disturbed from roosting areas. This has been addressed for the Waitata and Richmond salmon farms by requiring the establishment of a buffer zone around Boat Rock Point where King Shags may sometimes been seen.

In accordance with requirements of the consent condition 10 below, the consent holder will not operate any vessel associated with the marine farm within 100m of Boat Rock Point (Figure 4) unless in the case of emergency work arising from the need to protect life or limb or prevent loss or serious damage to property or minimise or prevent environmental damage.

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[3] Robertson, H.A; Dowding, J.E.; Elliott, G.P.; Hitchmough, R.A.; Miskelly, C.M.; O'Donnell, C.J.F.; Powlesland, R.G.; ; Sagar, P.M.; Scofield, R.P.; Taylor, G.A. (2013). Conservation status of New Zealand birds, 2012. *New Zealand Threat Classification Series* 4. Department of Conservation, Wellington. 22 p.

King Shags - Buffer Area and Management Plan

10. *..... a buffer area of 100m shall be maintained from the King Shag roosting site in the vicinity of the marine farm, as at the date of the commencement of this consent, within which no ship movements associated with the marine farm shall occur.*

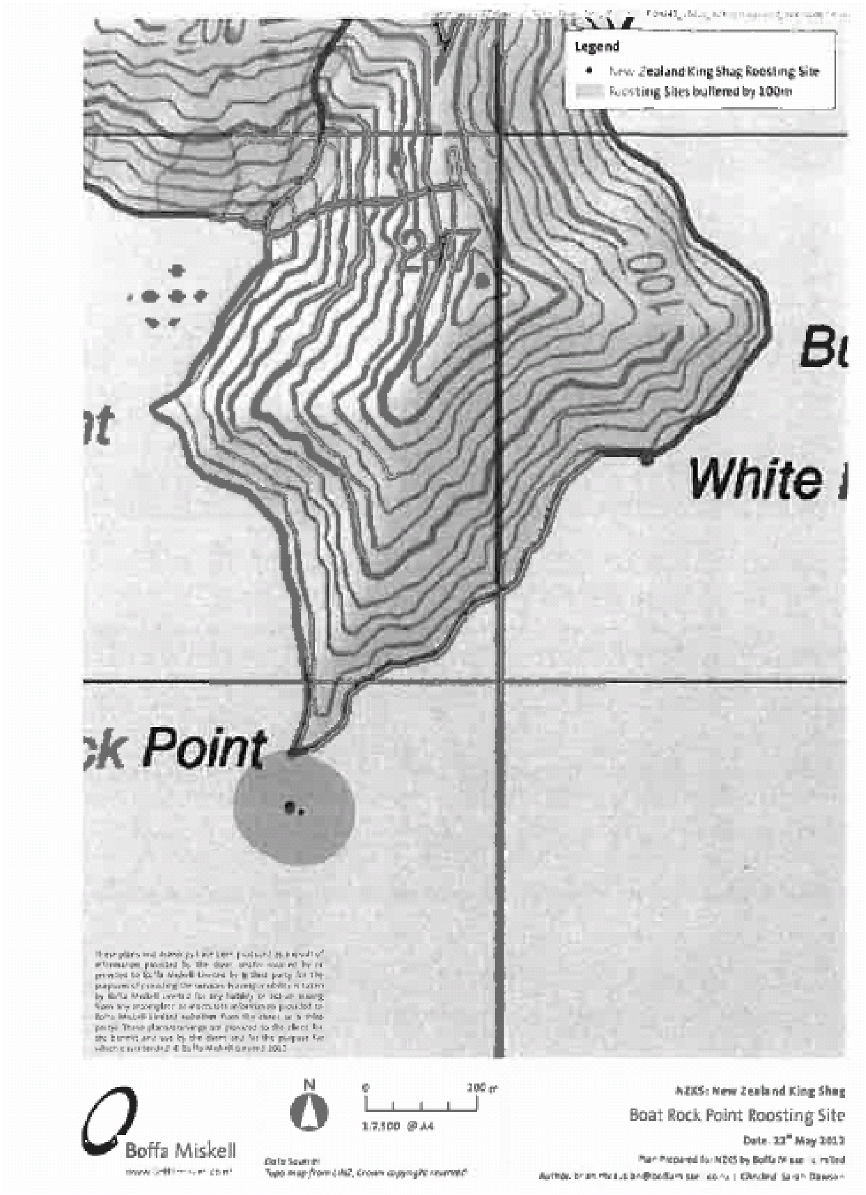


Figure 4 – Buffer area of Boat Rock Point Roosting Site[4]

[4] Decision Document – Appendix 9 – 13 March 2013 http://www.marlborough.govt.nz/Services/Property-File-Search.aspx

5 Objectives

The consent holder has prepared this KSMP in accordance with the requirements of the resource consent conditions. The consent conditions establish the following objectives for the KSMP.

11. *"The objective of the KSMP shall be to ensure that the establishment and operation of the new salmon farms do not result in a reduction in the population of King Shag in the Marlborough Sounds. This with particular regard to the Duffers Reef colony. This plan shall be provided to the Council prior to the first discharge of feed to the marine farm, with copies being provided to the Department of Conservation and the members of the Tangata Whenua Panel.*

The KSMP shall require:

a) Surveys of the numbers of King Shag in the Marlborough Sounds no less than once every three years. The first survey shall be undertaken prior to the first discharge of feed to the marine farm. All survey results are to be provided to the Council, Department of Conservation and the Tangata Whenua Panel within three months of completion of the survey, and posted on the King Salmon website.

b) In the event that a statistically significant decline of King Shag numbers ($p<0.05$) has occurred since the previous survey, the consent holder shall investigate whether the operation of the marine farm is causing or contributing to the decline.

c) A response mechanism is to be implemented if the marine farm is found to be causing or contributing to the decline in King Shag numbers. Such mechanism to include but not be limited to immediate changes to marine farm management practices including a reduction in feed or stocking levels."

6 King Shag Monitoring

While monitoring should focus on the Duffers Reef colony, monitoring data from other colonies are needed in order to give statistically relevant information in the long term and to account for natural or external influences.

A simulation study was conducted by MacKenzie (2014) to investigate the power of different survey designs to detect declines of a specified magnitude (between 1% - 5% per annum). Based on the recommendations from MacKenzie (2014), the following monitoring and management actions have been adopted for this KSMP:

a) Aerial survey techniques will replace boat-based surveys as the primary method for detecting changes in King Shag populations.

b) Aerial surveys replicating the baseline survey will be initially conducted once every three years (triennial) and will always include Duffers Reef, Trio Islands, White Rocks, Sentinel Rock, Rahuinui, Stewart Island, Hunia Rock and Tawhitinui. Potential new colonies will be included in future surveys if identified.

c) If monitoring data indicate a population decline (in total or at Duffers Reef specifically) of 3% per annum or more:

(i) Analysis will be undertaken to determine if salmon farming is causing or contributing to the decline, notably by assessing relative changes (e.g. bird numbers, adult/juvenile ratios, and breeding success) at Duffer's Reef versus more distant colonies. Further and different types of surveys may be needed to help assess cause and effect in this regard, and,

(ii) Aerial surveys will be undertaken annually.

d) If salmon farming is found to be causing or contributing to any decline (refer to 6c & 6f) in King Shag numbers, changes to marine farm management practices will be implemented immediately to address the decline. As noted in the consent conditions, the response will "*include but not be limited to immediate changes to marine farm management practices including a reduction in feed or stocking levels*." In order to arrive at a suitable response, consultation with the Department of Conservation will occur.

e) The change in survey frequency (annual) will improve the power of the monitoring programme to detect annual declines that can still have substantial cumulative impacts.

f) If further annual monitoring data indicate an ongoing decline, or any decline >5% in any one year, then annual surveys will continue and further analysis will be undertaken to determine if salmon farming is causing or contributing to the decline (as outlined in c(i) above)

g) Should annual monitoring detect a persistent recovery in the King Shag population (total and at Duffers Reef) over three consecutive years or more, aerial surveys will return to triennially.

h) Surveying is to be conducted in the early morning when the majority of the birds are still at the colony. The surveys will be conducted in the month of January or if not possible in that month at as near to January as possible. The birds have no territorial and nest duties around this time and leave late in the day compared to the breeding period between March and August so are more easily counted.

i) Flights should be slightly lower than those undertaken in February 2015 to improve clarity of the images.

j) A water based survey of the Duffers Reef colony will be carried out as close to the aerial survey as possible to confirm bird numbers and identify the time of first departures.

k) A declining population on Duffers Reef compared with increasing numbers at the other colonies would be a trigger to initiate more detailed research to help understand what might be causing these population changes.

l) Numbers of king shags using Duffers Reef should be compared with the numbers using other breeding sites to assess population trends over time.

m) Direction of departure information (Waitata Reach versus Forsyth Bay / Beatrix Bay) may be recorded at Duffers Reef colony while conducting any water based (boat) surveys to collect information that may be relevant to determining broad-scale changes of King Shag foraging in response to environmental changes in Waitata Reach.

7 Survey Results from February 2015

An aerial survey was conducted on 11 February 2015 of the known King Shag colonies in the Marlborough Sounds. The eight colonies surveyed were: Duffers Reef, Trio Islands, White Rocks, Sentinel Rock, Rahuinui, Stewart Island, Hunia Rock and Tawhitinui. This census was the first time that the entire known population has been counted within one hour in one day.

In total, it has been assessed that there was a total population of 839 (Figure 5) King Shags present in February 2015. This higher number compared to the 645 individuals estimated from previous surveys (1992 – 2002) is most likely the result of better accuracy of the aerial survey technique compared to boat surveys, though an increase in the total number of shags cannot be entirely ruled out. The synchronized count of all colonies in one morning and the inclusion of colonies that have not been counted before, provides the most accurate population estimate ever

Duffers Reef is now the largest colony of King Shags and Rahuinui colony has now surpassed Sentinel Rock as the fourth biggest colony.

The total numbers of King Shags at each colony, based on counts of individual shags seen in photographs taken on the aerial survey, are presented below. Three independent experts; Graeme Taylor, David Melville and Rob Schuckard, assessed the photos with the following outcomes:

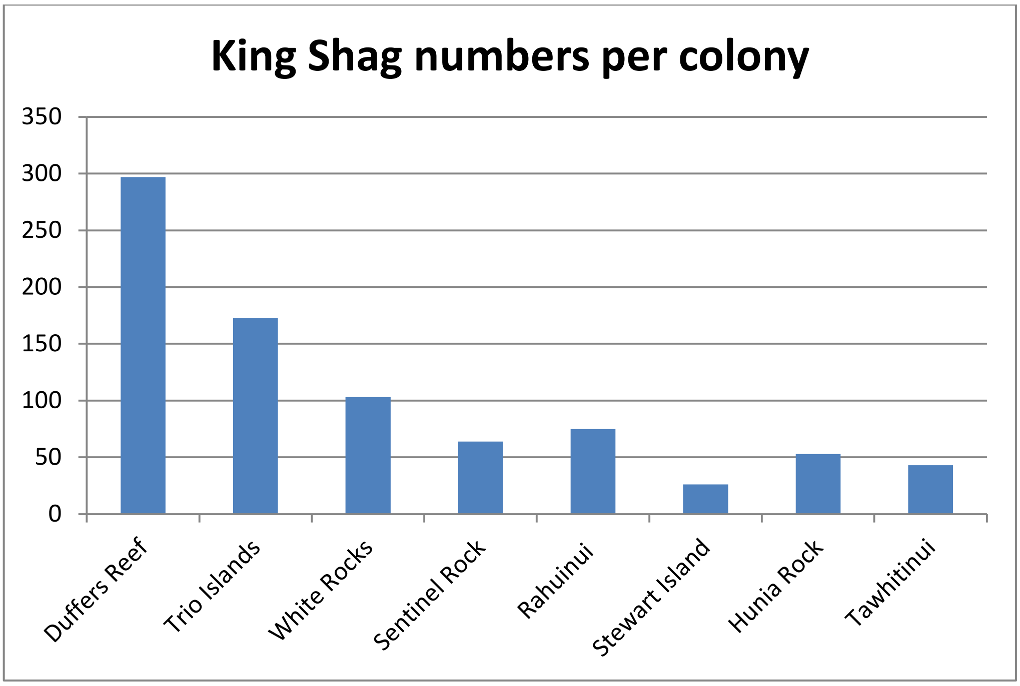


Figure 5 – King Shag numbers per colony

	King Shag numbers per colony
Duffers Reef	297
Trio Islands	173
White Rocks	103
Sentinel Rock	64
Rahuinui	75
Stewart Island	26
Hunia Rock	53
Tawhitinui	43
Total	**839**

Table 2 – King Shag numbers per colony.

Additional water (boat) based survey's, before and after the aerial survey, for Duffers Reef were conducted to provide confidence regarding the accuracy of the aerial survey and establish the time of first departure to be sure that the census was completed when all birds were attending the colony.

The aerial survey results will be used as a baseline for measuring potential effects of the activity of the salmon farms in the Waitata Reach on the King Shag population. If necessary the monitoring protocol may be reviewed. The survey results will include both aerial and water (boat) based survey information.

The survey information will be published in the ornithological journal for New Zealand Birds, Notornis.

8 Review

This King Shag Management Plan will be reviewed by the working group subsequent to the first three year monitoring event, and as necessary thereafter.

Appendix 1 - Proteus Wildlife Research Consultants – Darryl I MacKenzie

King Shag Population Modelling and Monitoring

Report prepared by:
Darryl I. MacKenzie

September 10, 2014

Proteus
wildlife research consultants

Contents

Executive Summary

Population Modelling

- Analyses of colony counts for king shags suggest the population has been relatively stable from 1994-2002.
- A 4-stage population model is used (chicks, year 1 birds, year 2 birds and adults) and the stable age distribution determined for a range of demographic parameter values.
- By comparing the results of the population model to collected count data, it would be reasonable to expect annual adult mortality for king shags to be between 0.10-0.15, which is similar to that estimated for other shag species.

King Shag Monitoring

- Consent condition 11 stipulates that "The objective of the KSMP shall be to ensure the establishment and operation of the marine farm does not result in a reduction in the population of King Shag in the Marlborough Sounds, with particular regard to the Duffers Reef Shag colony." This has been interpreted as suggesting that while monitoring should focus on the Duffers Reef colony, other colonies also need to be monitored.
- Such an approach is seen as beneficial to all parties in that it provides information on the wider population allowing possible possible changes at the Duffers Reef colony to be put into the context of changes across the whole population.
- It is recommended that consent condition 11.b be interpreted as suggesting that the effect of the marine farm operations on king shag populations should be investigated after a statistically significant decline is detected using data collected from the entire monitoring period, not just in successive surveys which could be an alternative interpretation. It will be very difficult to detect declines of <3% per annum using the information from only successive surveys.
- A simulation study was conducted to investigate the power of different survey designs to detected declines of a specified magnitude (between 1% - 5% per annum). The results of the simulation study provide the basis of the below recommendations.
- Assuming consent condition 11.b allows all of the data from the beginning of the monitoring programme to be used to determine the statistical significance of a decline, it is recommended that:

- surveys are initially conducted once every three years, with the Duffers Reef and 3 nearest colonies (Sentinel, Stewart Island and Trio Islands) surveyed in the same year within a relatively short timeframe, unless it is expected that any decline may exceed 5% per annum in which case more frequent surveys should be conducted. If the initial monitoring data indicates there may be a small decline of <3% per annum, then annual surveys should be undertaken, even if the decline is not statistically significant. This suggested change in survey frequency will improve the power of the monitoring programme to detect small annual declines that can still have substantial cumulative impacts.
- if a cost effective programme can not be developed for the 4 king shag colonies, then a minimum design is to monitor the Duffers Reef and Trio Island colonies. However, by reducing the scope of the programme lessens ones ability to draw conclusions about changes at the Duffers Reef colony in the context of the wider king shag population (e.g., dispersal from Duffers Reef to smaller colonies).
- surveying should be conducted in the early morning when the majority of the birds are still at the colony, and at times of the year when the population is likely to be most stable over time. Multiple counts have been been conducted previously at each visit, and this should be continued.
- direction of departure information be recorded at Duffers Reef colony while conducting the count surveys to collect information that may be relevant to determining broad-scale changes in king shag foraging behaviour that may occur due to changes in the water clarity and quality in the Waitata Reach.
- should consent condition 11.b be interpreted as statistical significance is required from successive surveys, then 3 surveys should be conducted of each colony within a relatively short timeframe (e.g., a month) each survey year to reduce the uncertainty in the count for that year.

- It is suggested that alternative methods of counting to boat-based surveys be considered, e.g., photographs from an UAV or small fixed-wing aircraft may provide a more accurate count from a higher vantage point with sufficient camera resolution, and prove more cost effective.

1 Population Modelling

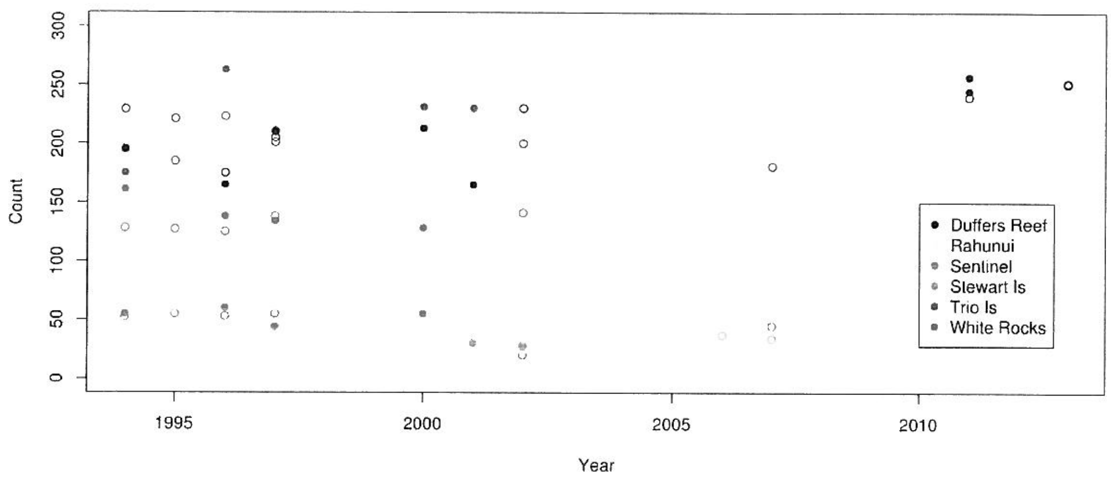
1.1 Analysis of Existing Count Data

Counts of the number of king shags at six known colonies (Duffers Reef, Rahuinui, Sentinel, Stewart Island, Trio Island and White Rocks) for the period 1932-2013 was supplied by Rob Schuckard. Data collected prior to 1994 has been excluded here due to differences in survey protocols which are likely to have resulted in major undercounting of the number of birds at the colony (Schuckard, 2006). Consistent methodology has been used since 1994 although some counts were conducted later in the day when some fraction of the birds are absent from the colony. Figure 1 presents the total early-morning counts for each colony for the period 1994-2013. Counts were consistently made at the 4 main colonies (excluding Rahuinui and Stewart Island) during 1994-2002, few surveys during the mid- to late-2000's and a number of surveys at Duffers Reef since 2011. As all six colonies have not been surveyed each breeding season in a systematic fashion, two analyses have been conducted here.

The first uses the counts from the 4 main colonies during 1994-2002 and the second just examines the data from Duffers Reef from 1994-2013. All analyses have been conducted using log-linear regression, implemented as a generalised linear model in the statistical package *R* with Poisson distributed data and a log-link function for regression coefficient estimation. That is, simple linear regression of the count data on the log-scale. Differences among colonies were allowed in the general magnitude of the counts, and among colony differences in the trends were also considered. Seasonal differences in the counts were assumed to be the same (on the log-scale) in each year and for all colonies.

Note that the purpose of the analyses is not to examine the data for definitive statistical evidence of a trend in king shag numbers, but to quantify some aspects of the data to aid with the population modelling.

Figure 1: Early morning counts of king shags at each colony from 1994-2013. Filled symbols indicate breeding season counts, and open symbols are non-breeding season counts.



1.1.1 4 main colonies; 1994-2002

Two regression models were fit to the data; one assuming the same trend at each colony (Figure 2) and a second assuming a different trend (Figure 3). The second model is significantly better ($\chi^2 = 14.85$, $df = 3$, p-value= 0.02) suggesting a downward trend at the Sentinel colony, an upward trend at Trio Island and relatively stable at the other two colonies (Figure 3). Using the predicted count values from each model, the total count can also be predicted for each year, even in years when some colonies were not surveyed (Figure 4). While the model with different trends for each colony suggests a slight decline over this period, the magnitude of the decline is relatively small and decreasing. Overall, these results are similar to those of Schuckard (2006) who concluded the population is relatively stable over this time period.

Figure 2: Early morning counts of king shags at each colony from 1994-2002. Filled symbols indicate breeding season counts, and open symbols are non-breeding season counts. Lines indicate estimated trends assuming the same trend for all colonies. Solid lines for breeding season counts and dashed lines for non-breeding season counts.

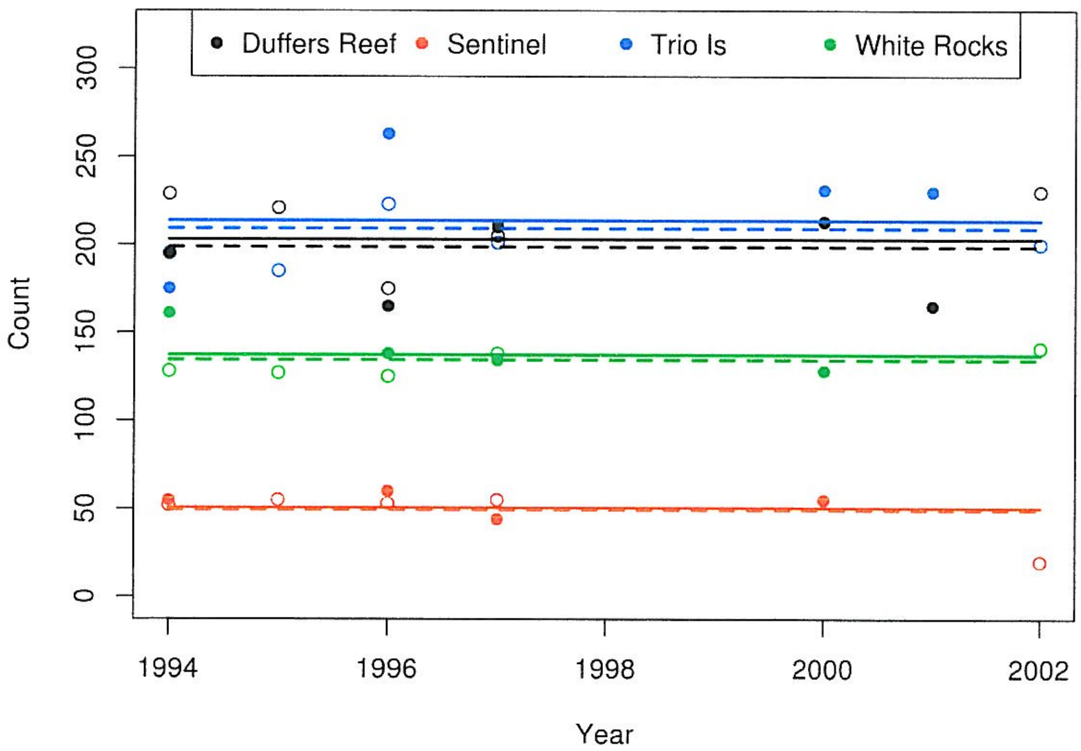


Figure 3: Early morning counts of king shags at each colony from 1994-2002. Filled symbols indicate breeding season counts, and open symbols are non-breeding season counts. Lines indicate estimated trends assuming different trends for each colony. Solid lines for breeding season counts and dashed lines for non-breeding season counts.

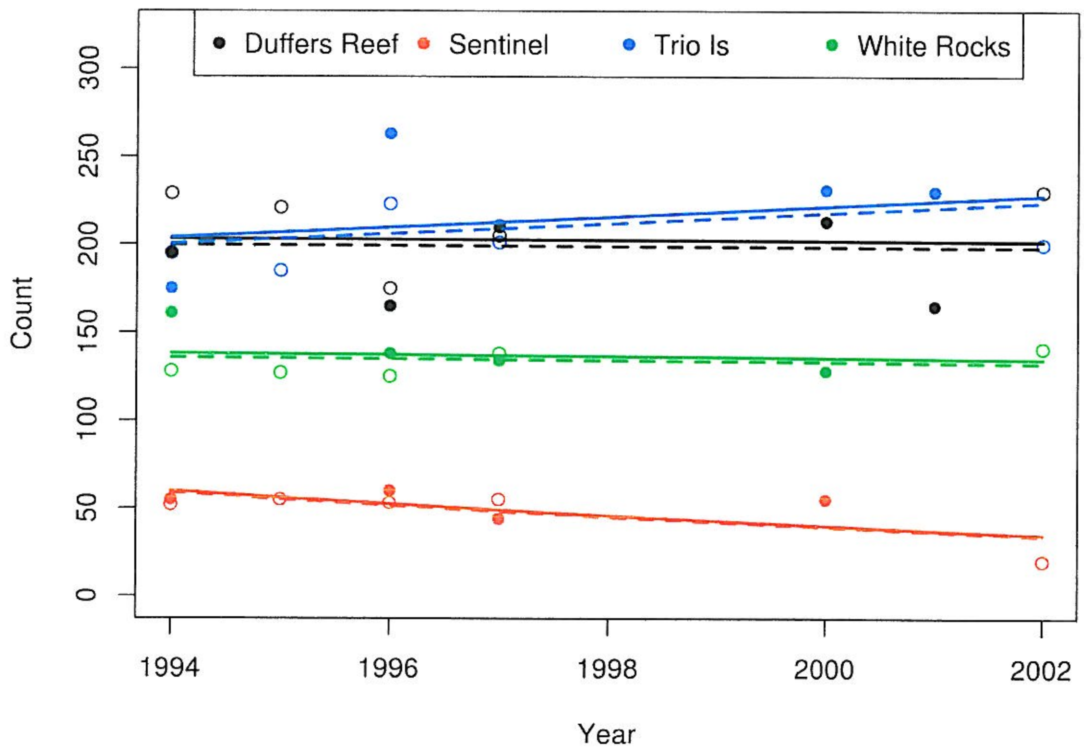
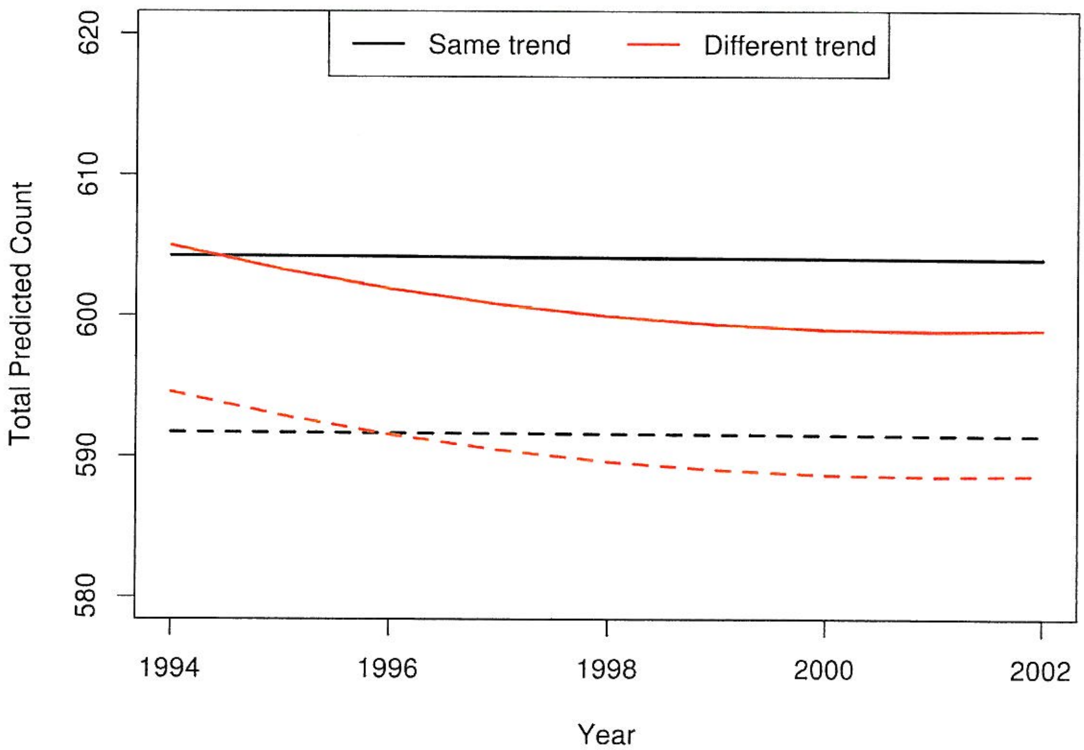


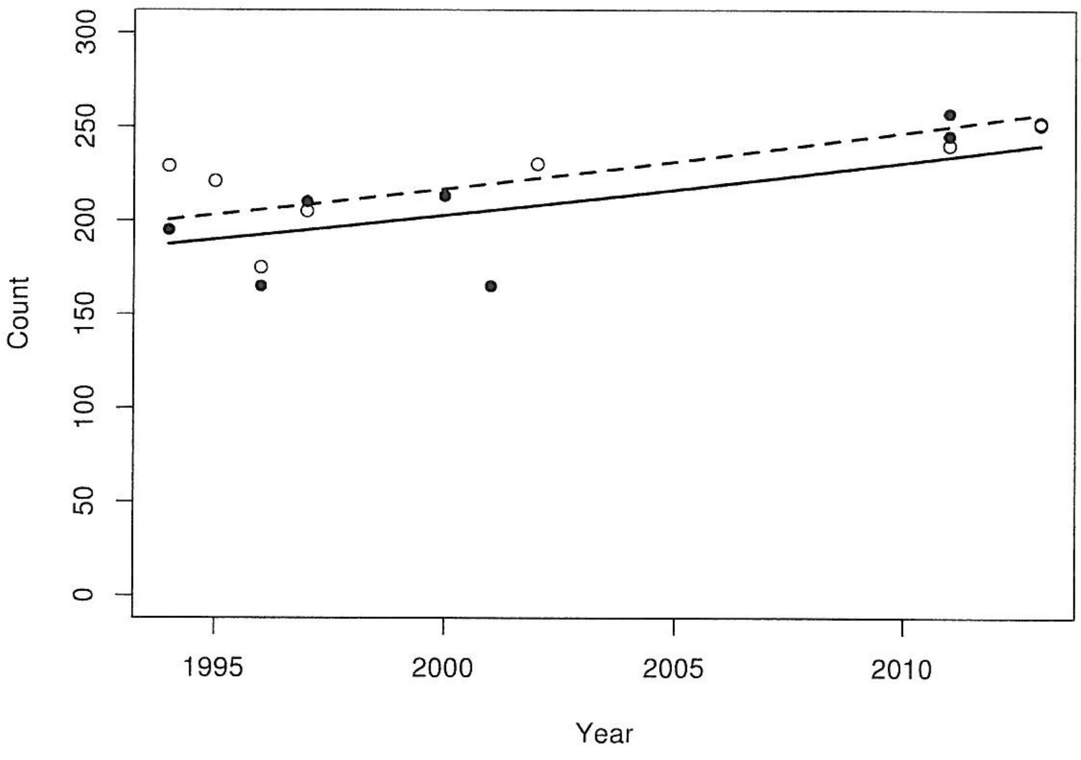
Figure 4: Predicted total count of king shags for the four colonies (Duffers Reef, Sentinel, Trio Island and White Rock) during 1994-2002 from models assuming either the same trend across all colonies (e.g., Fig 2) or a different trend at each colony (e.g., Fig 3). Solid lines indicate estimated breeding season counts and dashed lines for non-breeding season counts. Confidence intervals have not been included in the figures, but there is a large degree of overlap suggesting no evidence of substantial differences.



1.1.2 Duffers Reef; 1994-2013

A separate analysis of the early morning counts from Duffers Reef would suggest an increase during 1994-2013 (Figure 5). The early morning counts since 2011 are clearly higher than those from the 1990's and early 2000's, though the lack of early morning counts in the mid- to late- 2000's means it is impossible to determine whether there has been a gradual change (as indicated by the trend) or a more sudden change due to an influx of birds. Without information from the other colonies it is also difficult to ascertain the overall relevance of this increase in whether it is indicative of a general increase across all colonies, or the result of some inter-colony movement of birds. Birds redistributing themselves amongst colonies would be one possible explanation for why the previous analysis indicated different trends for different colonies, and was also noted by Schuckard (2006).

Figure 5: Early morning counts of king shags at Duffers Reef from 1994–2013. Filled symbols indicate breeding season counts, and open symbols are non-breeding season counts. Solid lines indicate estimated trends for breeding season counts and dashed lines for non-breeding season counts.



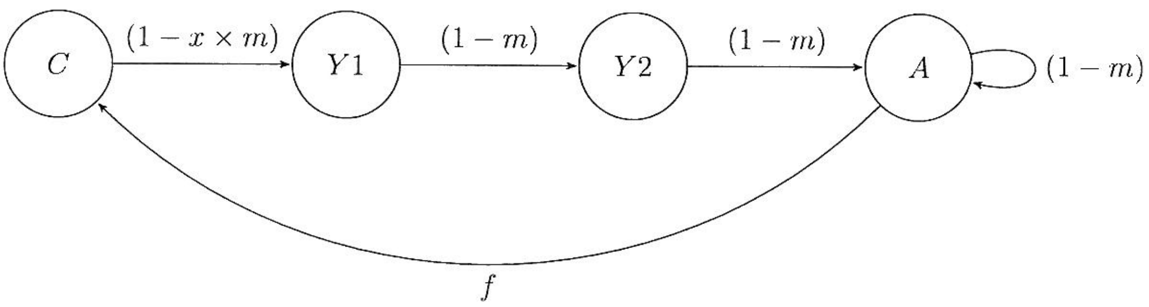
1.2 A Population Model

Here a relatively simple population model has been assumed with four life stages:

1. chicks (C).
2. 1-year old birds ($Y1$).
3. 2-year old birds ($Y2$).
4. breeding adults (A).

Figure 6 is a schematic of this population model, which assumes that all birds are potential breeders at age 3. The mortality rate m has been assumed equal for all birds older than 1 year, and first year mortality may be higher by a factor of x. The chicks life stage represents the age at which they maybe included in the survey counts, presumably post fledging. As such, the per capita fecundity rate f is a combination of adult breeding probability, nesting attempts, clutch size, nesting success and fledging success. Decomposing f into it's components is not relevant at this point.

Figure 6: Population model for king shags. Circles represent the life-stages and arrows indicate the transition rate between stages; where m is the mortality probability, x is a multiplier to allow higher first-year mortality, and f is the per capita fecundity rate.



Schuckard (2006) and the above analysis would suggest the king shag population is relatively stable over this timeframe. Assuming the population is in equilibrium suggests that the number of adult birds that die each year ($N_A m$) will be replaced by an equal number of 2-year old birds that survive to become adults ($N_{Y2}(1-m) = N_A f(1-x \times m)(1-m)^2$), and that the proportion of the population in each stage class is constant over time. Based upon this structure, the first result implies that the per capita fecundity rate is:

$$N_A m = N_A f(1-x \times m)(1-m)^2$$
$$f = \frac{m}{(1-x \times m)(1-m)^2}$$

Further, it can be shown that the proportion of the population in each stage class would be:

C: $\dfrac{m}{Z(1 - x \times m)(1 - m)^2}$

Y1: $\dfrac{m}{Z(1 - m)^2}$

Y2: $\dfrac{m}{Z(1 - m)}$

A: $\dfrac{1}{Z}$

where, $Z = \dfrac{m}{(1 - x \times m)(1 - m)^2} + \dfrac{m}{(1 - m)^2} + \dfrac{m}{1 - m} + 1$. Note that these proportions do not depend upon f. Figures 7-9 and Figures 10-12 present what proportion of the population would be in each stage class for different levels of adult mortality, where the first year mortality multiplier is 1, 2 or 3. Both sets of figures contain the same information, but presented in different formats. As would be expected, as adult mortality increases a greater proportion of the population would be younger birds. Similarly, as first-year mortality increases chicks constitute a greater proportion of the population.

From these results the expected number of chicks produced given a particular total population size (N) and mortality scenario can be obtained as: Np_C, where p_C is the proportion of the population in the chick class. Figure 13 presents the expected level of chick production for a total population size of 250 or 650 and a range of mortality scenarios.

Figure 7: Proportion of king shag population in each stage class for different levels of adult mortality where first year mortality is equal to adult mortality ($x = 1$).

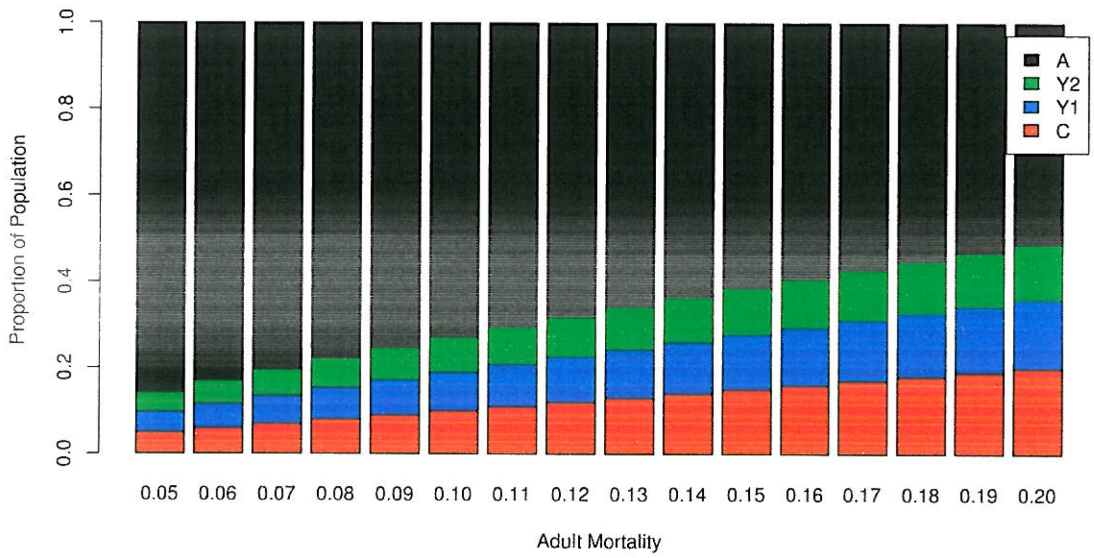


Figure 8: Proportion of king shag population in each stage class for different levels of adult mortality where first year mortality is twice adult mortality ($x = 2$).

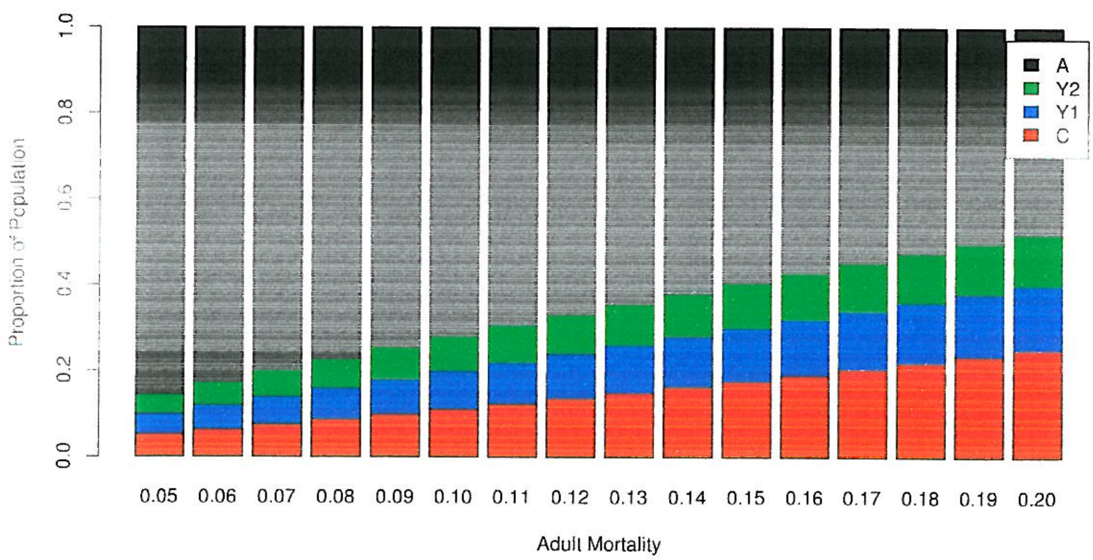


Figure 9: Proportion of king shag population in each stage class for different levels of adult mortality where first year mortality is thrice adult mortality ($x = 3$).

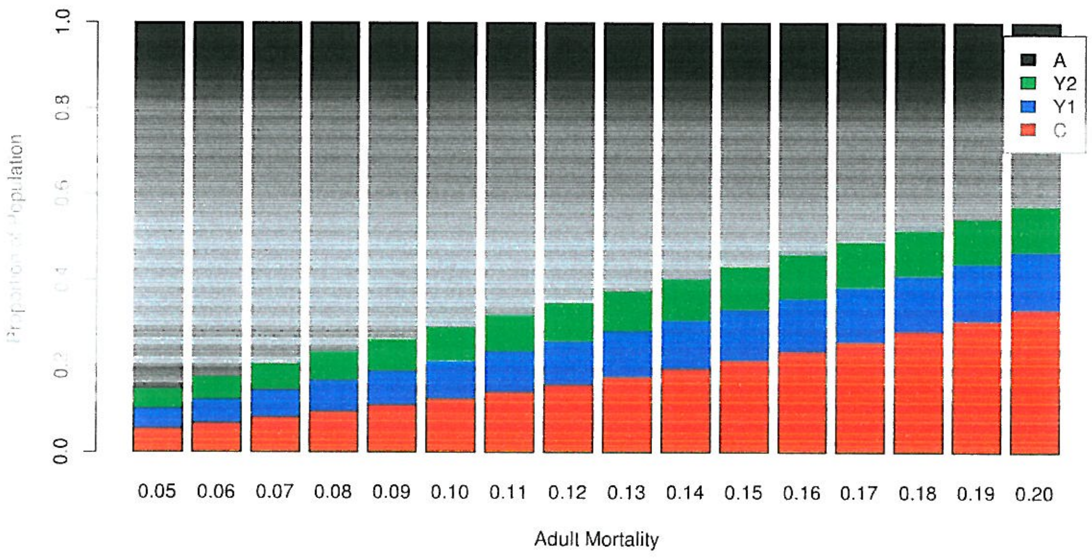


Figure 10: Proportion of king shag population in each stage class for different levels of adult mortality where first year mortality is equal to adult mortality ($x = 1$).

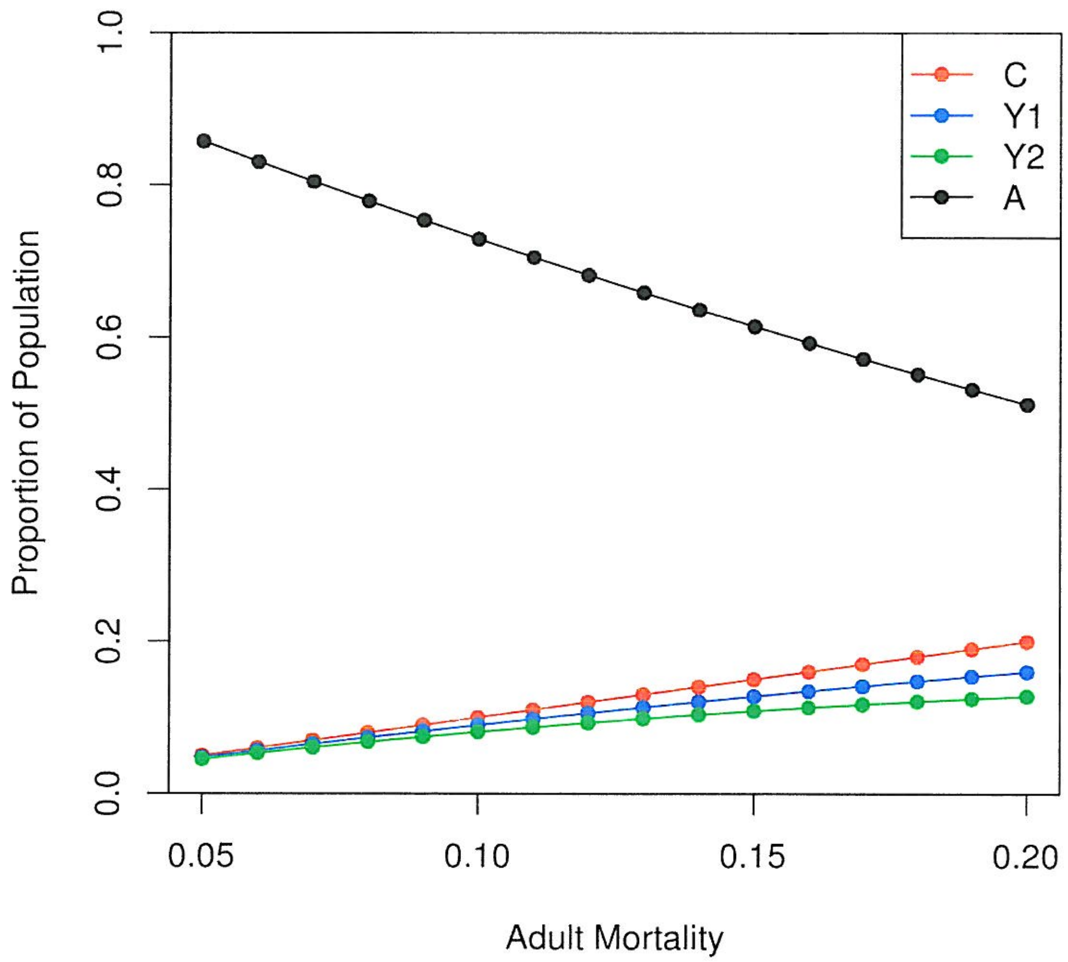


Figure 11: Proportion of king shag population in each stage class for different levels of adult mortality where first year mortality is twice adult mortality ($x = 2$).

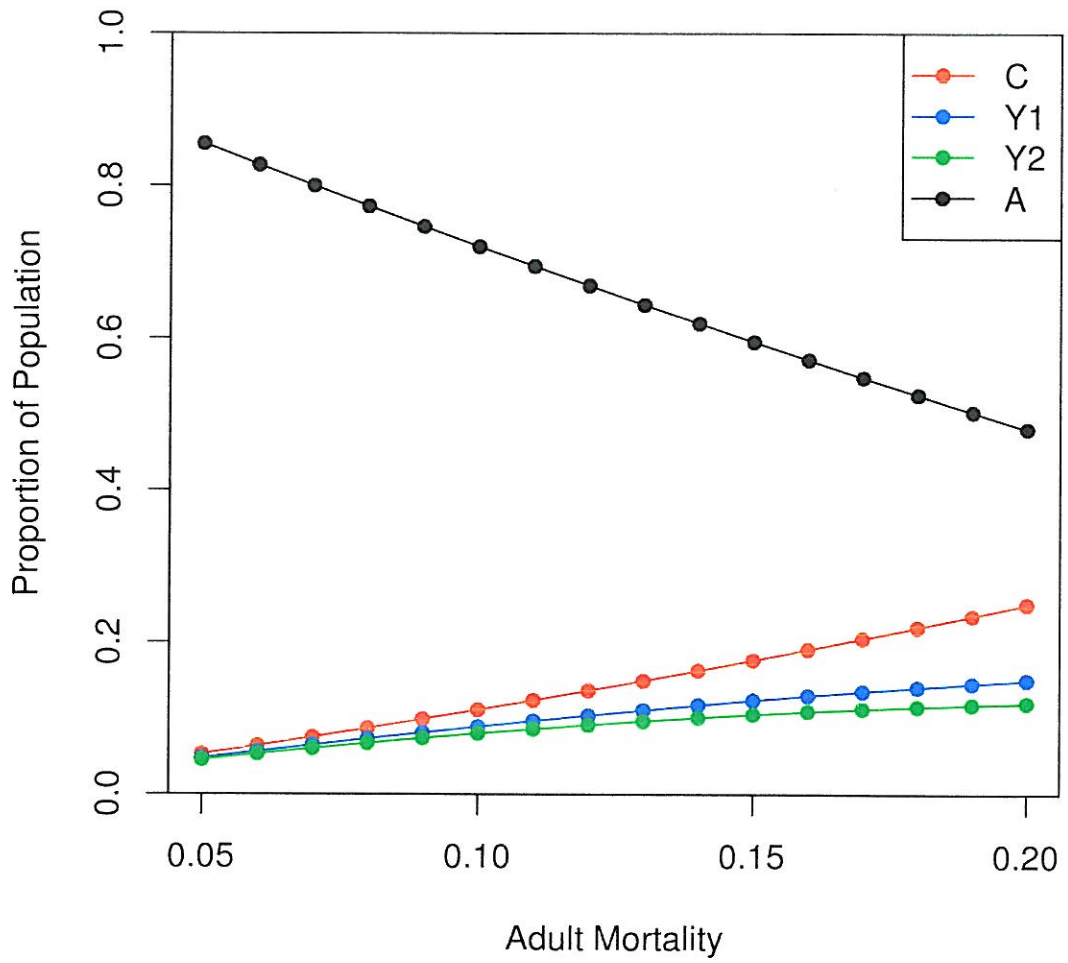


Figure 12: Proportion of king shag population in each stage class for different levels of adult mortality where first year mortality is thrice adult mortality ($x = 3$).

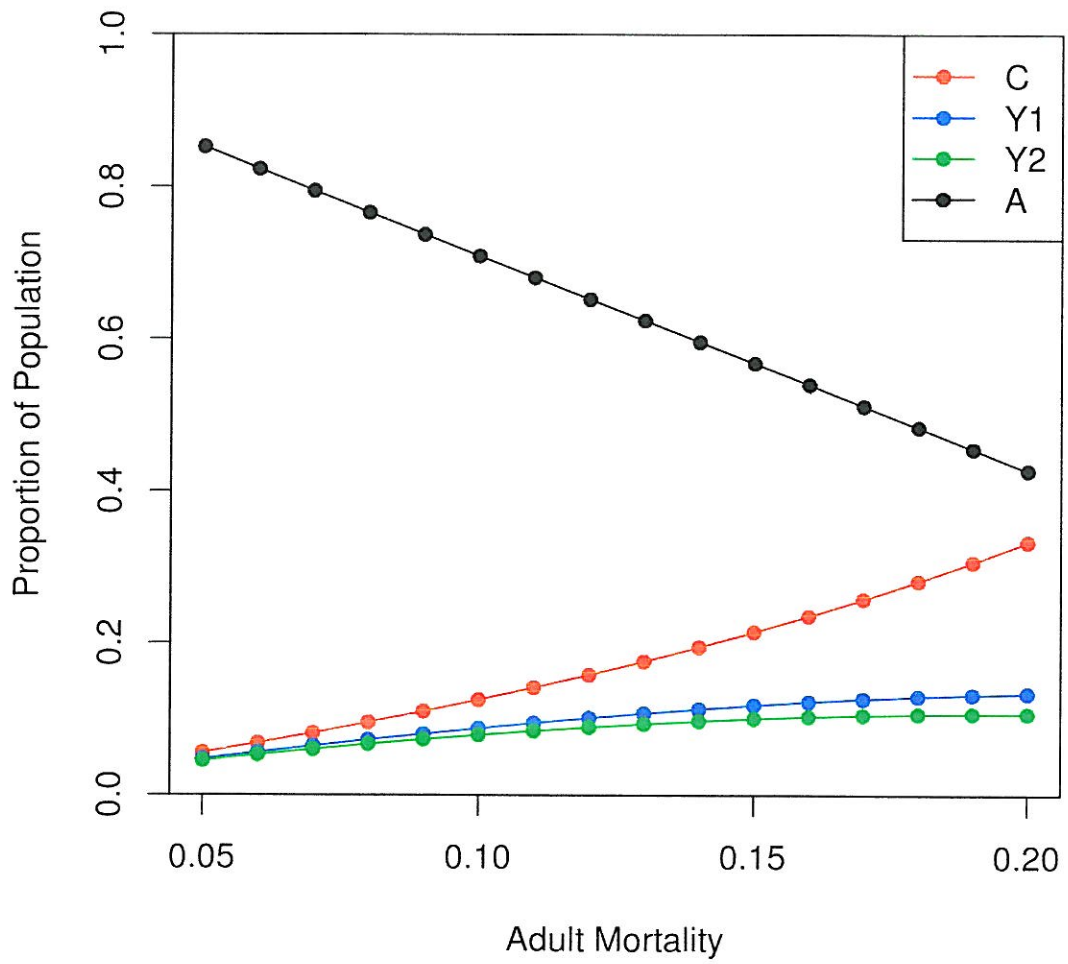
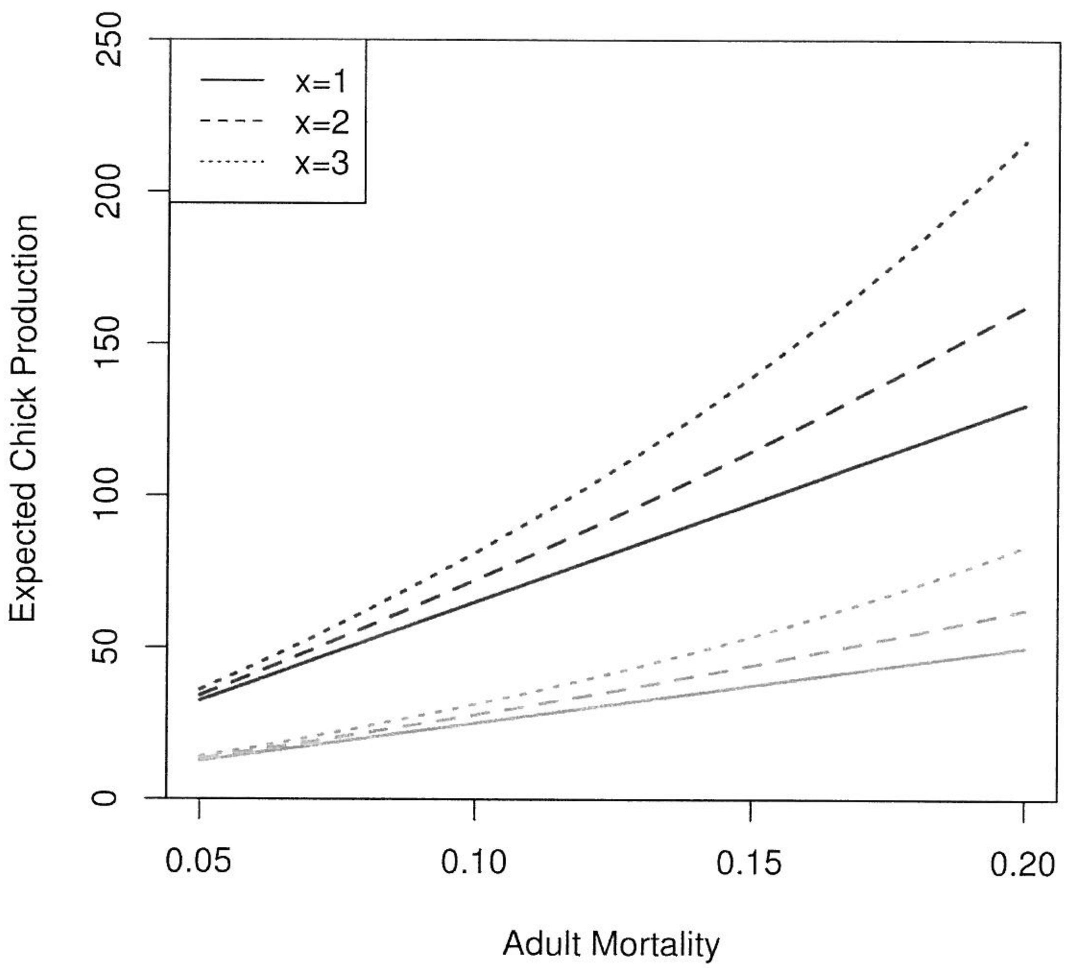


Figure 13: Expected level of king shag chick production as a function of adult mortality for a total stable population size of 250 (light grey lines) or 650 (dark grey lines). Solid, dashed and dotted lines indicate different level of first-year mortality factors (x = 1-3 respectively), i.e., solid line indicates expected number of chicks produced per annum to maintain a stable population size if chick mortality is equal to adult mortality, while dotted line is the expected number required if chick mortality is 3 times adult mortality.



1.3 Discussion

The assumption that the king shag population is relatively stable appears to be well supported by the available data. While there are no estimates for demographic parameters for king shags, there are some for other shag species. The European Commission notes for the European shag[1] that a "Danish study" found mortality rates between 0.25-0.68 for first year birds (post fledging), 0.13 for second year and 0.12 for adults, with "Other studies" indicating adult mortality of between 0.10-0.20. They also report typical age of first reproduction between 2-4 years. Unfortunately they do not provide references for the studies. Harris et al. (1994) also report an adult mortality probability of 0.12 for European shags on the Isle of May, and note other studies have found similar values for European shags (0.15, Aebischer 1986, Isle of May; 0.17 Potts et al. 1980, Farne Islands), flightless cormorant (0.12, Harris 1979, Galapagos) and blue-eyed shag (0.10, Cobley 1989, Signy Island). Fortin et al. (2013) estimated mortality probabilities of 0.56, 0.24 and 0.19 for first-year, second-year and adult European shags (respectively) in western France. For double-crested cormorants in the Great Lakes region of North America, Seamans et al. (2012) found average morality probabilities of 0.55 for hatch-year birds, 0.16 for second-year birds and 0.12 for after second-year birds. These studies would suggest that it might be reasonable to expect adult mortality rates in the range of 0.10-0.20 for king shags and age of first reproduction at about three years. Note that the fecundity rate f encompasses the fact that not all adult birds may be breeders in any year.

Figure 13 would suggest that for a total population size of 650 birds, with the assumed population structure, the chick production would have to be between approximately 60-200 chicks per year if adult mortality is between 0.10-0.20. Schuckard (2006) reported the number king shag chicks to be in the range 48-60 and, if these numbers are accurate, that would suggest adult mortality is likely to be closer to 0.10, which is in keeping with his conclusion. However, the potential for undercounting must also be considered, particularly if the fraction of birds missed is different for chicks relative to other age classes. If relatively more chicks are missed during the surveys, then the number of chicks would be higher and therefore adult mortality could be higher and a stable population size still be maintained.

[1] http://ec.europa.eu/environment/nature/cormorants/faq.htm

2 King Shag Monitoring

2.1 Introduction

The Board of Inquiry included the following consent condition with respect to king shags monitoring (as supplied by R. Schuckard):

11. The consent holder shall, in consultation with the Department of Conservation and the members of the Tangata Whenua Panel (refer to condition 77) prepare and implement a King Shag Management Plan (KSMP). The consent holder shall engage an independent person (or persons) with appropriate knowledge and expertise to prepare the KSMP. The objective of the KSMP shall be to ensure the establishment and operation of the marine farm does not result in a reduction in the population of King Shag in the Marlborough Sounds, with particular regard to the Duffers Reef Shag colony. This plan shall be provided to the Council prior to the first discharge of feed to the marine farm, with copies being provided to the Department of Conservation and the members of the Tangata Whenua Panel. The KSMP shall require:

a) Surveys of the numbers of King Shag in the Marlborough Sounds no less than once every three years. The first survey shall be undertaken prior to the first discharge of feed to the marine farm. All survey results are to be provided to the Council, Department of Conservation and the Tangata Whenua Panel within three months of completion of the survey, and posted on the King Salmon website.

b) In the event that a statistically significant decline of King Shag numbers ($p < 0.05$) has occurred since the previous survey, the consent holder shall investigate whether the operation of the marine farm is causing or contributing to the decline.

c) A response mechanism is to be implemented if the marine farm is found to be causing or contributing to the decline in King Shag numbers. Such mechanism to include but not be limited to immediate changes to marine farm management practices including a reduction in feed or stocking levels.

While the consent conditions specifically refer to the Duffers Reef colony, it clearly states that "... the establishment and operation of the marine farm does not result in a reduction in the population of King Shag in the Marlborough Sounds, ...". In order to reliably determine whether a reduction occurs at the scale of the Marlborough Sounds will require a broader monitoring programme of the king shag population, that encompasses most, if not all, of the breeding colonies. The White Rock and Rahuinui Island colonies are furthest removed from Duffers Reef colony, therefore, in the event of any disturbance-related dispersal from Duffers Reef colony it would be most likely that birds may resettle at one of Trio Island, Stewart Island or Sentinel Rock colonies. These 4 colonies should therefore be prioritised for monitoring.

Limiting the monitoring programme to only the Duffers Reef colony, or the Duffers Reef and one other 'control' colony (i.e., a colony that is assumed to be not impacted by the development of the marine farm), will not enable any effect on the king shag population in the Marlborough Sounds to be properly ascertained, nor could any change in the Duffers Reef colony be put into the context of overall changes in the whole population. It should be noted that by surveying the whole population, circumstances that could result in a local decline at Duffers Reef, but no net effect on the total population (e.g., by inter-colony movement of individuals) could be identified. Furthermore, the reactionary approach to monitoring given in condition 11.b will be problematic for assessing what, if any, contribution the operation of the marine farms have to a decline in the king shag population due to the potential lack of baseline information. That is, by not starting to collect relevant information for determining any potential effect of the marine farms on the king shag population until after a statistically significant decline has been detected, it is impossible to determine what the 'natural' conditions may have been like prior to the decline or in the absence of the farms.

With good baseline information it is possible to demonstrate what could be considered as a 'normal' range of observations, thereby enabling a more rigorous assessment of any potential effect on the king shag population. While the collection of baseline, and ongoing, data prior to the identification of a statistically significant decline maybe more costly, it does provide an element of risk mitigation for all parties. Potential issues and concerns may be resolved more quickly when relevant data is available, rather than protracted discussions with little data or delays while additional data is collected.

Through discussions with R. Schuckard, the main concerns that the establishment of the marine farms could have on the king shag population in the Marlborough Sounds is the direct loss of foraging habitat localised around the marine farms sites, or broader changes in foraging behaviour caused by changes to the water quality in the Waitata Reach from the marine farm operations. If foraging is a limiting factor for the population, then changes in the areas available for foraging could ultimately lead to a decline in the size of the king shag population at the Duffers Reef colony through death or movement, and possible a general decline within the Marlborough Sounds.

In the remainder of this section a range of designs for a general monitoring programme are investigated for their power to detect a decline in the king shag population, potential designs for the collection of foraging information, discussion of the various results and designs, followed by a series of recommendations.

2.2 Design for Changes in Population Size

King shags are an easily disturbed species making physical capture difficult (R. Schuckard, *pers. comm.*). Given the small population size (approximately 650 birds), and their conservation status of 'Nationally Endangered', banding studies to enable mark-recapture estimates of population size and survival would likely be overly intrusive as a substantial fraction of the known population would have to be banded to provide sufficient information. The most pragmatic option for monitoring would therefore be to use a count of the number of birds at a colony, as has been used previously (Schuckard, 2006).

Count-based metrics do have certain limitations, in particular they represent an unknown fraction of the total number of birds in the population hence are often regarded as an index to population size rather than an absolute measure (Williams et al., 2002). This aspect of count data has been well demonstrated for king shags by Schuckard (2006) who showed that the fraction of birds on the colony varies with time of day, hence historic counts at colonies may have only counted approximately 40% of the total population as they were conducted later in the day. While it is expected that most birds will be on the colony in the early morning, it is possible that some birds will not be counted due to their position relative to the observer (e.g., obscured by another bird or terrain), and counting of chicks that have not begun to develop their fledging plumage may be especially problematic (R. Schuckard, *pers. comm.*). Therefore, even early morning counts should not be regarded as completely accurate and they will display some degree of variation. A bigger concern is when the fraction counted changes over time in a systematic fashion (e.g., gradually increases or decreases) as then any change in the population size is going to be confounded with the the changing proportion of birds counted, possibly resulting in misleading conclusions. However, given the openness of the king shag colonies, and previous stability of the counts, this is not anticipated to be a major concern at this stage provided that counts are consistently conducted in the early morning.

The prime considerations here are therefore the frequency and number of years of surveying of the king shag population in the Marlborough Sounds. Table 1 presents the range of general survey designs that have been investigated via simulation, indicating the frequency with which surveys are conducted and the number of years since the baseline survey at which an assessment is made as to whether there has been a significant decline. For example, with annual surveys and 9 years after baseline, a total of 10 surveys have been conducted. While with triennial surveys and 9 years after baseline a total of 4 surveys have been conducted. Simulations were conducted to investigate the power of

Table 1: General survey designs considered in the simulation study for detecting a decline in king shag population size. Frequency is the frequency with which surveying is conducted and Years Since Baseline is the number of years since the baseline survey was conducted at which evidence of a decline is assessed in the simulation. Note that in practice an annual assessment would be made with an annual surveying frequency, but this as note been done here to speed up the simulations.

Frequency	Years Since Baseline
Annual	1,2,3,6,9,12
Biennial	2,4,6,8,10,12
Triennial	3,6,9,12

these general designs to detect a decline of a given magnitude at a 5% significance level (as stated in condition 11.b). Power is the probability of correctly detecting the decline at that significance level, hence higher values indicate a more effective design.

The size of the four king shag colonies in each year was assumed to be a random value from a Poisson distribution, with a given expected population size (i.e., over many simulated sets of data the average of the random values should equal the expected population size). Different scenarios were investigated where the expected population size was defined to decline at a rate of 1%, 2%, 3%, 4% or 5% per year. The percentage decline is in terms of the expected population size of the previous year, hence is not additive. That is, a 1% decline per year for 10 years is not a 10% decline from the initial population size (although it is close in this case). The initial expected population size for each colony was calculated using the results from a Poisson regression analysis on the 1994-2002 count data which was similar to that used previously in the population modelling section where the trend was the same for all colonies (i.e., Figure 2). These results where then used to predict the expected population size in 2014 which was used as the initial value for the simulations. Two sets of scenarios were considered for a comparison, either monitoring the four colonies (so approximately 500 birds) or only the Duffers Reef colony (approximately 200 birds; although noting more recent surveys indicate the population may currently be closer to 250 birds). A plot of the expected population sizes are given in Figure 14.

Once the random values were generated for a simulated set of data, these were regarded as counts of either the total population in the four colonies or only Duffers Reef colony accordingly, and examined for a significant decline using Poisson regression and a one-sided z-test on the estimated trend. A z-value less than -1.645 was deemed to be a significant result at the 5% level. For each scenario, 5000 simulated sets of data were generated and power was calculated as the proportion of simulations that yielded a significant result. The counts were generated for an initial (i.e., baseline) year, then 12 further years. The

Figure 14: Expected population sizes used in the simulations to assess the power of each design for detecting a decline at the 5% significance level.

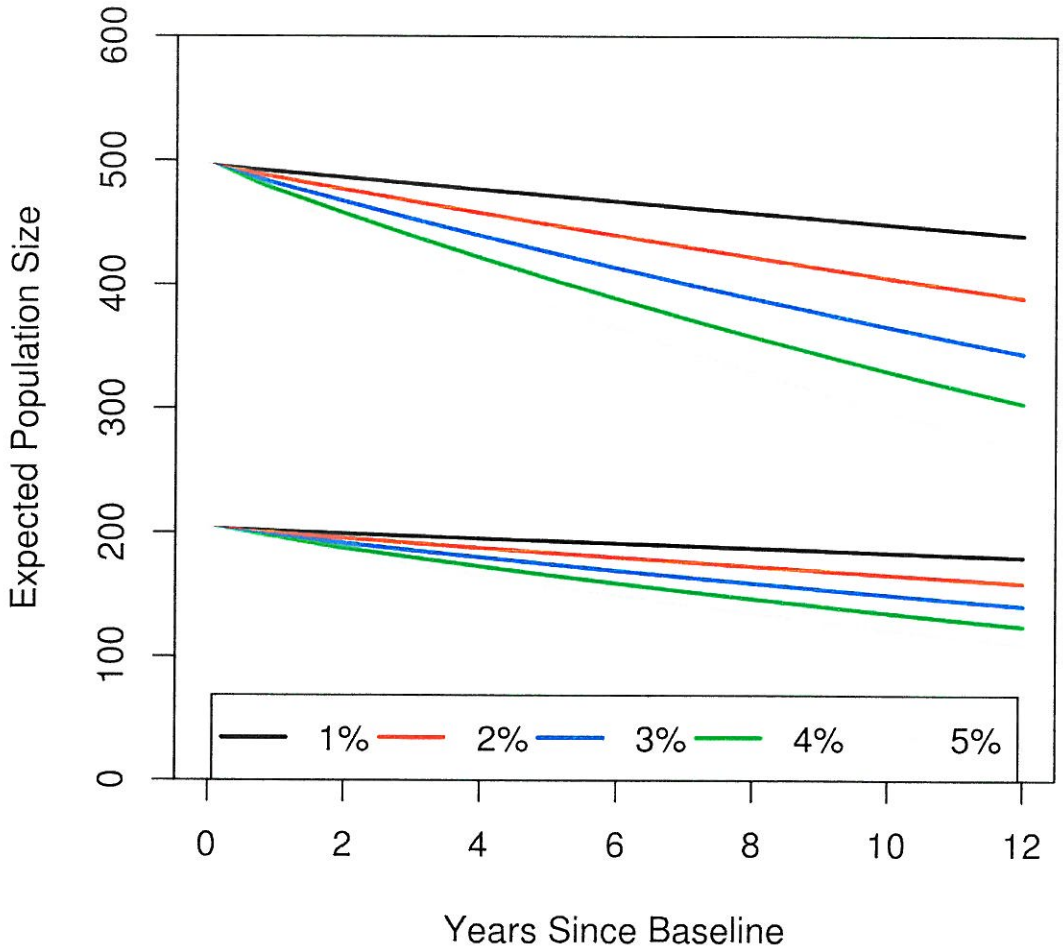
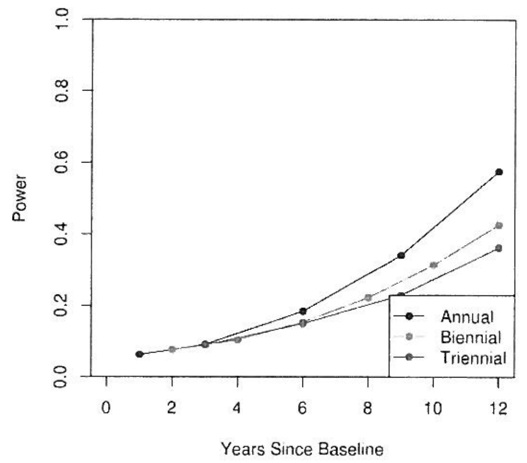
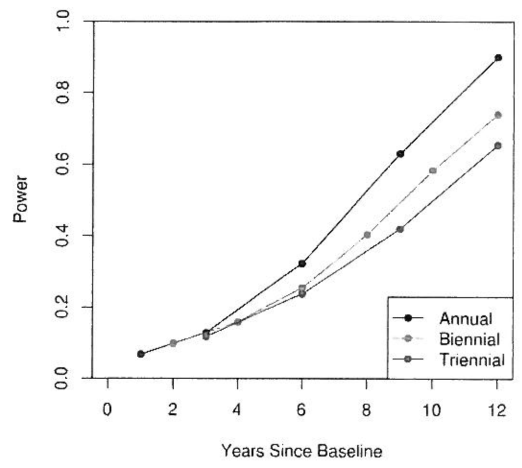


Figure 15: Power to detect 1% annual decline using Poisson regression with a 5% significance level, for a variety of general designs. Two scenarios are presented where initial expected population size is 200 birds (e.g., Duffers Reef Colony only) or 500 birds (e.g., total population in four colonies).



(a) 200 birds



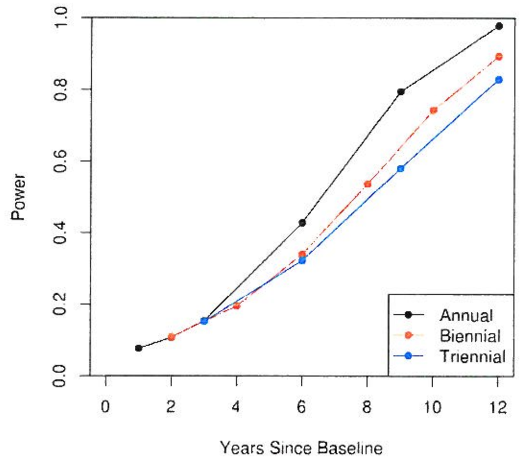
(b) 500 birds

data for the different general designs given in Table 1 was obtained by partitioning the data as required.

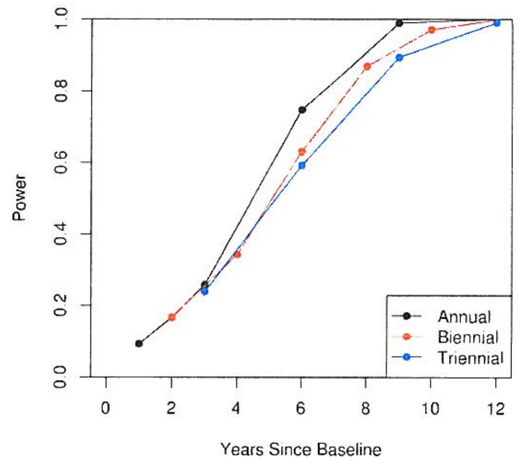
The results of the simulation study are given in Figures 15-19. Power to detect a decline increases as the time since beginning the monitoring programme increases, and is also higher when monitoring the larger population. Higher power is achieved by monitoring annually, rather than biennially or triennially, although the relative difference between the three general approaches reduces as the magnitude of the decline increases in successive figures. Overall, power increases as the magnitude of the decline increases.

In addition to assessing the power to detect a significant decline overall, the power to detect whether the trend at the Duffers Reef colony is significantly lower (with $p < 0.05$) than the trend at the Trio Island colony was also assessed. Data was simulated similar to above where a decline of a given magnitude was specified for the Duffers Reef colony, but no decline at the Trio Islands colony. This is the type of analysis that would be conducted to determine whether a decline at Duffers Reef is greater compared to the rest of the population. Results are given in Figure 20 with a similar pattern to that obtained previously, although the power to detect that the decline at the Duffers Reef colony is greater than at Trio Islands is less than then power to detect an overall decline at Duffers Reef (panels a of Figures 15-19).

Figure 16: Power to detect 2% annual decline using Poisson regression with a 5% significance level, for a variety of general designs. Two scenarios are presented where initial expected population size is 200 birds (e.g., Duffers Reef Colony only) or 500 birds (e.g., total population in four colonies).

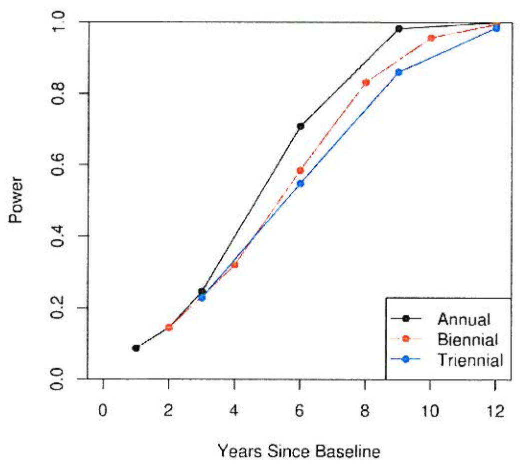


(a) 200 birds

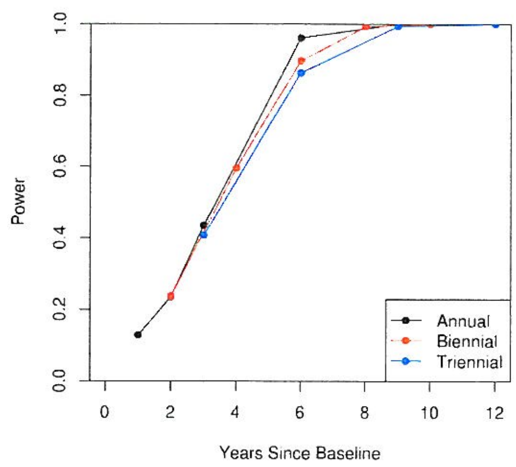


(b) 500 birds

Figure 17: Power to detect 3% annual decline using Poisson regression with a 5% significance level, for a variety of general designs. Two scenarios are presented where initial expected population size is 200 birds (e.g., Duffers Reef Colony only) or 500 birds (e.g., total population in four colonies).

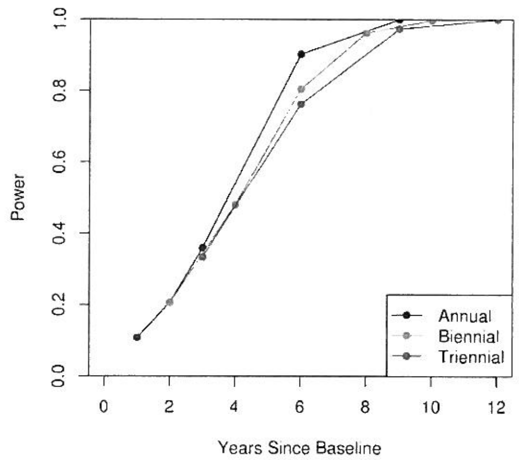


(a) 200 birds

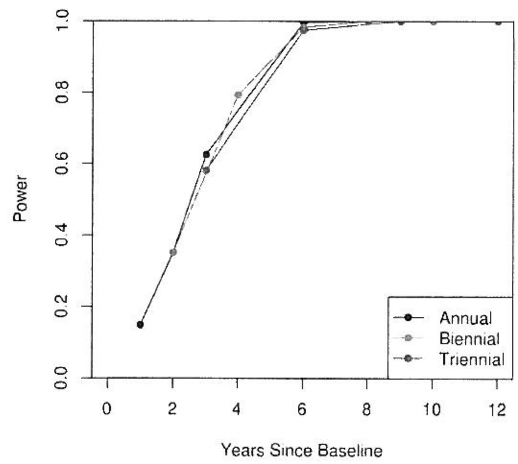


(b) 500 birds

Figure 18: Power to detect 4% annual decline using Poisson regression with a 5% significance level, for a variety of general designs. Two scenarios are presented where initial expected population size is 200 birds (e.g., Duffers Reef Colony only) or 500 birds (e.g., total population in four colonies).

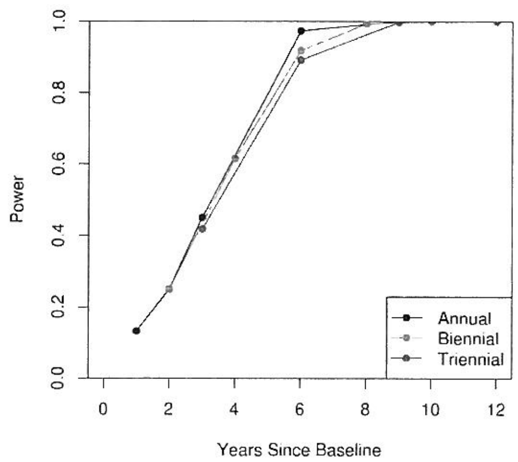


(a) 200 birds

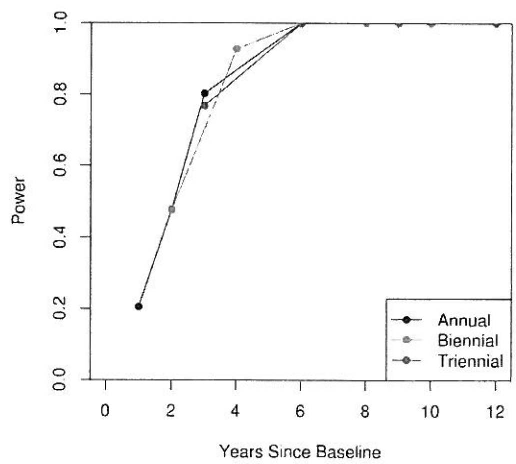


(b) 500 birds

Figure 19: Power to detect 5% annual decline using Poisson regression with a 5% significance level, for a variety of general designs. Two scenarios are presented where initial expected population size is 200 birds (e.g., Duffers Reef Colony only) or 500 birds (e.g., total population in four colonies).

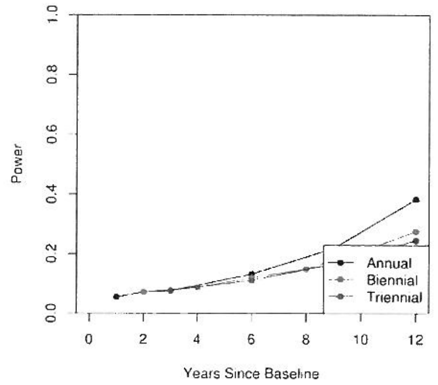


(a) 200 birds

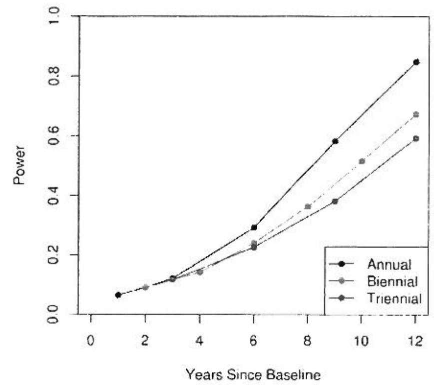


(b) 500 birds

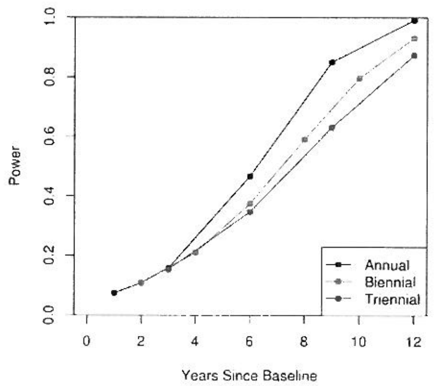
Figure 20: Power to detect a greater decline at the Duffers Reef colony compared to Trio Islands colony using Poisson regression with a 5% significance level, for a variety of general designs. Simulations were conducted such that there was a decline at the Duffers Reef colony of the indicated magnitude, but no decline at the Trio Island colony.



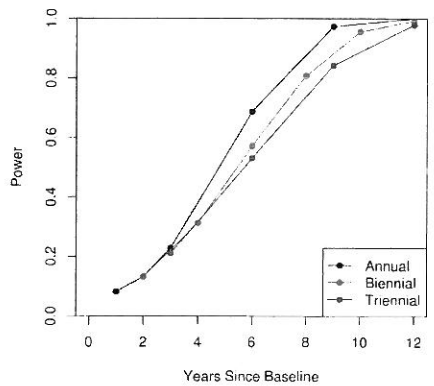
(a) 1% decline



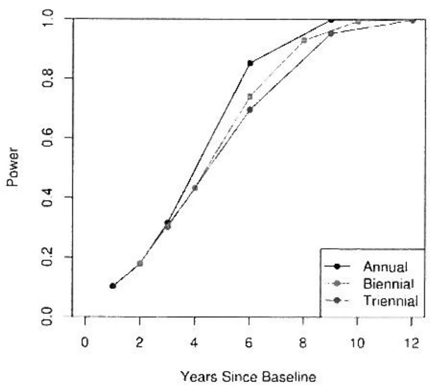
(b) 2% decline



(c) 3% decline



(d) 4% decline



(e) 5% decline

2.3 Monitoring Foraging Behaviour

One of the possible impacts of the marine farms on the king shag population is changes in foraging behaviour, either directly through exclusion of the shags from the area immediately around the marine farms, or, at a broader scale, through a decrease in the water quality and clarity in the Waitata Reach. Assuming a non-invasive form of monitoring (i.e., no handling of birds), there are some options available for collecting data to assess whether the farms may be having some impact at these different scales.

For the localised scale, the farm locations could be monitored to determine whether there is a change in the level of use by king shags before and after the establishment of the farm. Remote cameras could be used to collect the information using a predetermined schedule of photos or short video clips (although a pulse of photographs, e.g., 100 at 5 second intervals, may require less storage than a video clip over the same time period). An obvious advantage of remote cameras is that they can be left at a site and collect data over a longer time period than with a specific monitoring survey where people have to remain at the site. Cameras should be located to give a clear shot that encompasses the general vicinity of the proposed farm to document bird activity. In addition to the farm sites, other control sites would also be monitored to provide a comparison against the potentially impacted sites. Without an preliminary information on the likely level of use of an area by king shags it is difficult to provide some reliable statistical advice on the frequency of monitoring, number of control sites, etc. If the present level of use is low (e.g., a few birds sighted per day) then statistical significance of an effect may be difficult to achieve unless use becomes essentially zero. Furthermore, even if an effect is documented, some consideration must be given to how applicable that result may be in terms of impact on the king shag population; is a localised exclusion caused by the physical structure of the marine farm likely to have a major effect on the population overall? Even if it is deemed to have low applicability in this particular case, documentation of a localised effect would be valuable when considering cumulative impacts for other marine farms.

To assess potential broader scale effects on the king shag Duffers Reef colony, direction of departure information could be used to determine whether birds display some avoidance of Waitata Reach. There is existing information which clearly demonstrates that the majority of the birds tend to depart the colony heading south-east, south, south-west or west, and relatively few depart in the other directions. The proportion of birds departing to the south-west and west (combined) was 41%, 37%, 54% and 49% in 1991, 2001, 2011 and 2013 respectively. Presuming that those birds that depart to the south-west or west are primarily foraging in the Waitata Reach, a major reduction in the proportion of birds departing in these direction may suggest avoidance of the reach as a foraging area. Given the range for the observed proportions so far, the reduction would likely have to be quite marked (e.g. a proportion of near 20%) to be statistically significant, or a gradual decline in the proportion over time.

2.4 Discussion

To make use of the above simulation results, some consideration has to be given to what level of power a monitoring programme should be designed for. In doing so it can be useful to consider the possible consequences of various decisions that could be made during the monitoring programme (i.e., successfully or failing to detect a decline), the level of risk and potential costs associated with each one. This may require input from a number of groups when done properly, although it is suggested that aiming for a monitoring programme with a power of 0.80 would not be considered unreasonable.

In comparing the simulation results for the different numbers of monitored birds (200 vs 500 birds), it must be remembered that if any effect of the marine farms is only on the Duffers Reef population, the magnitude of the effect will be reduced at the scale of the 4 colonies combined. For example, if there is a 5% annual decline at Duffers Reef and the other colonies are unaffected, that would amount to a 2% annual decline across the 4 colonies. However, if the other colonies are also affected to some degree, then the overall decline will be higher.

The difference in the power of the three general designs of using annual, biennial or triennial surveying is only really apparent for smaller declines, particularly when monitoring the whole population. For example, with a 1% annual decline (Figure 15) surveying annually for 10 years achieves a power of 0.80, while approximately 15 years would be required with triennial surveying. Overall this would amount to approximately a 10% decline in the initial population size in 10 years versus an overall decline of 14% over 15 years. Whereas with a 5% annual decline (Figure 19), surveying for 3 years would provide a design with power of 0.80 for both annual and triennial surveying, at which point the overall decline would be 14%. If monitoring was only of a smaller population with approximately 200 birds initially, a longer period of monitoring is required before achieving a power of 0.80, hence the impact on the population will be comparatively greater.

Trying to detect whether a decline is significantly greater at one colony compared to another colony, or other colonies, is a subtly and substantially different question to ask than whether the one colony has a decline overall. To assess the former question, a comparison must be made of two estimated quantities, both of which have some degree of uncertainty. Therefore, the level of uncertainty associated with the *difference* between them will be greater than the uncertainty in either of the individual quantities. This added uncertainty leads to a reduction in power. However the benefit, which is more difficult to numerically quantify, is to be able to identify that something different is happening at the one colony compared to elsewhere.

It must be kept in mind that if a design has a power of 0.80, that does not ensure that a decline of a given magnitude will be detected, there is a still a 0.20 probability that there could be a decline but it will go undetected. Furthermore, the realised power of a particular design could be different from it's intended value as there maybe alternative methods of analysis, other factors that get included in the analysis, etc., all of which may affect the ability to detect a decline in the real data. In addition, here the power to detect a consistent rate of decline has been investigated, which implies any effect of the marine farm is relatively instantaneous, and also consistent over time. In actually, any effect may gradually change with each stage of development hence a decline in the king shag population (if any) may also change. This should be kept in mind when analysing the monitoring data.

While the exact wording of condition 11.b could be interpreted as that there has to be a statistically significant decline between *successive* surveys before the consent holder investigates whether the operation of the marine farm is causing or contributing to the decline, this is not a reasonable or pragmatic use of the available monitoring data (i.e., by ignoring information from earlier surveys). The interpretation of the wording of condition 11.b used here is simply that "a statistically significant decline of King Shag numbers ($p < 0.05$) has occurred since the previous survey" means there was no statistically significant decline at the previous survey, but there is after the assessment following the present survey, and that in both cases all available data has been used to determine if there has been a decline. Clearly, this would be the most efficient use of the data that has been collected rather than only basing each assessment upon only the previous and present survey data. With the latter approach, subtle effects that cause a gradual decline will be very difficult to detect statistically as comparisons will only be made between successive surveys, and the information from earlier surveys is disregarded. For example, the power to detect a significant decline in successive surveys is given by the annual, biennial and triennial designs after 1, 2 or 3 years of monitoring since the baseline, respectively. The power to detect a decline only gets close to 0.80 in these three situations with triennial surveys and an annual decline of 5% when monitoring all 550 birds (Figure 19). That is, an overall decline in the population of 14% in successive surveys. With a 1% annual decline (Figure 15), the power is <0.15 for each of these three situations, meaning it is unlikely that the decline will be detected. The power could be improved by conducting multiple surveys per year of each colony, or by using higher p-values before a result is declared statistically significant (e.g., requiring $p < 0.10$, or $p < 0.15$). Although in this latter case, this also increases the possibility of incorrectly concluding there to be a decline.

In designing the fieldwork for performing the colony counts, some consideration should be given to alternatives to a boat-based count. For example, a small unmanned aerial vehicle (UAV) or drone with a camera may provide a better angle for obtaining an accurate count than the view obtained from the boat. A fixed wing UAV may have sufficient range to be operated from a land base and survey multiple colonies in the one morning. Aerial photographs could also be taken from a small fixed-wing aircraft (e.g., a Cessna 172) provided birds are not disturbed from the colony. Depending on camera resolution, this may also provide better information on chick numbers, particularly those that are still in the nest.

2.5 Recommendations

It is strongly recommended that Duffers Reef and the 3 nearest king shag colonies (Sentinel, Stewart Island and Trio Islands) are monitored to provide some indication about the state of the king shag population in the Marlborough Sounds, with particular regard to the Duffers Reef colony. Such a programme will provide the necessary context to reliably interpret a statistical significant decline at the Duffers Reef colony relative to the wider king shag population. If a cost-effective programme can not be developed for monitoring the 4 colonies, then a minimal design would be survey the Duffers Reef and Trio Islands colonies. One drawback in not monitoring all colonies is that potential change at those colonies (including possible increases) are unknown. It should be noted that if there is only an effect on the Duffers Reef colony causing a decline in shag numbers, the magnitude of the decline will be less at the population scale, or even possibly no decline if the effect of the marine farms is causing birds to disperse away from Duffers Reef. However, by having the data from multiple colonies allows an assessment as to whether a decline is the same or different for each colony.

From the results of the power study, it is recommended that colonies are initially surveyed once every three years, unless it is anticipated that any potential decline is likely to be much greater than the 5% decline used in the simulations. If the results of the triennial surveys suggest there may be a small decline of <3% per annum, then annual surveys should be conducted even if the decline is not statistically significant. The power of triennial surveys are similar to those of annual surveys for declines of around 5% per annum, while annual surveys have greater power to detect smaller declines. Increasing the frequency of the survey will improve the ability of the monitoring programme to detect more subtle declines that may still result in a substantial effect before being detected. All colonies should be surveyed at approximately the same time of year, in the same year, to provide an accurate snapshot of the population. When the surveys should be conducted in less important, provided it is consistently implemented. Although there may be certain times of year when the population is more stable over time (e.g., pre-breeding counts may be more stable than post-fledging as the latter may be more variable due to breeding success in a given year). Counts should be conducted early-morning while most birds are still at the colony, with multiple counts conducted each morning.

It is recommended that the wording of consent condition 11.b be interpreted such that all data can be used to determine whether there has been a statistically significant decline, not just the data in successive surveys. A smaller decline is going to be much more difficult to detect under the latter situation, but will nonetheless gradually degrade the population. If it is determined that statistical significance has to be shown in successive surveys, then it is recommended that each colony be surveyed 3 times per year within a relatively short timeframe (e.g., within a month), particularly if any effect is likely to be <3% decline per annum, to reduce the uncertainty in the count for that year.

Finally, it is recommended that direction of departure information is collected for king shags from the Duffers Reef colony when the count survey is conducted. This could be a useful source of information to assess potential broad-scale effects of the marine farms on the foraging behaviour of king shags from the Duffers Reef colony. Monitoring of the specific farm locations (and control sites) is not recommended at this point due to uncertainty in the relevancy of such information to determining population-scale effects of the consented marine farms. It is noted, however, that knowledge of localised-effects of marine farms on king shags (and other species) could be very relevant to future developments, especially when considering cumulative effects. Therefore the present development offers a unique opportunity for a pilot study into the localised-effects of marine farms in the Marlborough Sounds.

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