Abundance and population trends of mollymawks on Campbell Island

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Cover: View of Bull Rock South mollymawk colony from MP12 photopoint, Campbell Island.
Photo: Peter Moore, 8 October 1995

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CONTENTS

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ABSTRACT

Counts of nests in photographs taken since the 1940s and ground counts conducted during the 1990s are used to establish population trends over a 55-year period for Campbell (*Thalassarche impavida*) and grey-headed (*T. chrysostoma*) mollymawks (albatrosses) on northern Campbell Island (subantarctic islands, New Zealand). Repeat counts of photographs had coefficients of variation (CVs) of 6.6% and the main ground count methods had CVs of 3%–5%. Between the 1940s and 1990s there was an apparently continuous 82%–88% decrease (at 1.5%–2.7% p.a.) in nest numbers at three photographed grey-headed mollymawk colonies. Ground counts in 1995–97 recorded 7800 grey-headed mollymawk nests/yr (6200 with eggs during mid-October), representing a population of about 11 800 (biennially breeding) pairs. Extrapolating back from these data, there may have been 43 000 grey-headed mollymawk nests/yr in the 1940s. Environmental changes affecting the food supply are the most likely explanation for the long-term decline. One Campbell mollymawk colony showed an increase of 11% in nest numbers between the 1940s and 1966, a decrease of 47% by the 1980s, then a gradual recovery of 3.2% p.a. Extrapolation suggests there were about 31 300 Campbell mollymawk nests in the 1940s. There were 24 600 nests in 1995–97 (21 000 with eggs during mid-October). The large decrease in the late 1960s to early 1980s coincided with the peak in long-line fishing for southern bluefin tuna. Regular monitoring of mollymawk populations (preferably with a suite of species) is recommended; three consecutive years every decade is a minimum requirement. A multidisciplinary approach is needed to test links between environmental change and mollymawk population trends.

Keywords: *Thalassarche impavida*, *T. chrysostoma*, Campbell mollymawks, grey-headed mollymawks, albatrosses, photo counts, abundance, population trends, Campbell Island, subantarctic islands, New Zealand

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1. Introduction

Several of the world's albatross species declined in numbers over the second half of the 20th century, and for some, such as wandering albatross (*Diomedea exulans*[1]), this was linked to human fishing activities (Weimerskirch & Jouventin 1987; Croxall et al. 1990; Weimerskirch et al. 1997; Gales 1998). High numbers of albatrosses and other seabirds were accidentally killed during trawling and longline fishing in the New Zealand region (Bartle 1991; Murray et al. 1993), and although some mitigation procedures may have reduced the rate (Murray et al. 1993), bycatch continued (Manly et al. 2002, Robertson et al. 2004). Albatrosses caught in high numbers included the Antipodean (*D. antipodensis*) and Gibson's (*D. gibsoni*) albatrosses, and Campbell (*Thalassarche impavida*), Buller's (*T. bulleri*) and white-capped (*T. steadi*) mollymawks (albatrosses)[1]. It was not known, however, what impact there was on their populations as there was a general paucity of data on population size or trends for New Zealand albatross species (Taylor 2000).

Early estimates of albatross populations tended to be inaccurate (Tickell 2000). It was not until the 1970s–80s, when intensive research and annual counts began at British and French subantarctic islands, that more realistic figures were available. Other nations followed suit and many censuses were conducted of albatross islands (Gales 1998; Tickell 2000). Census methods varied depending on size of colony and accessibility. Generally, most censuses of albatross islands were raw counts of whole colonies of birds, where each nest was visited and tallied (e.g. Prince et al. 1994; Weimerskirch et al. 1997; Sagar et al. 1999). Other methods included averaged binocular counts of inaccessible colonies (e.g. Prince et al. 1994; Sagar et al. 1994), tallies of birds seen from vantage points (e.g. Dilks & Wilson 1979), counts of birds seen in photographs (e.g. Sagar et al. 1999; Huin 2001) or estimates combining colony area and nesting density (e.g. Thompson & Rothery 1991; Huin 2001).

Campbell Island (52° 29′ S, 169° 9′ E) lies 660 km south of New Zealand and 350 km southeast of the Auckland Islands (Fig. 1). Six albatross species, including three mollymawks, breed on the island. The most numerous is the annually breeding Campbell mollymawk (previously known as the New Zealand black-browed mollymawk *Diomedea melanophrys impavida*; Turbott 1990), which is endemic to Campbell Island (Marchant & Higgins 1990). In 1988 it was estimated there were 19 000–26 000 breeding pairs (Moore & Moffat 1990a). There are also small numbers (30–100 birds) of the closely related black-browed mollymawk *T. melanophrys* (Moore, Taylor & Amey 1997; Moore, Burg et al. 2001). The species has a widespread subantarctic breeding distribution, with a total breeding population estimated at 680 000 breeding pairs (Gales 1998;

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[1] This report follows the taxonomy proposed by Robertson & Nunn (1998), which recognised four genera and 24 species of albatrosses. Most recent authors have followed the proposed taxonomy but retained some of the old common names (e.g. Gales 1998). The smaller *Thalassarche* albatrosses are referred to throughout this report as mollymawks, following Robertson & Nunn (1998) and the New Zealand convention (Turbott 1990).

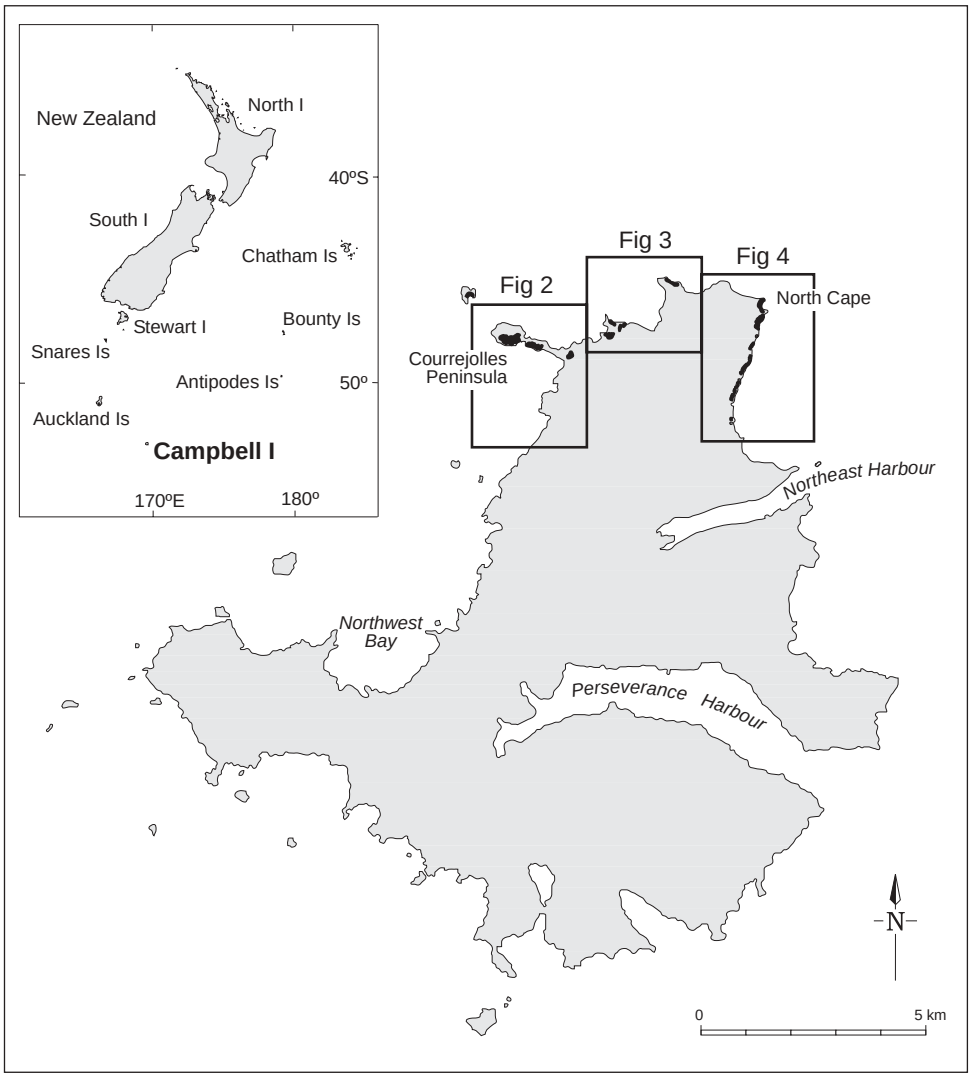
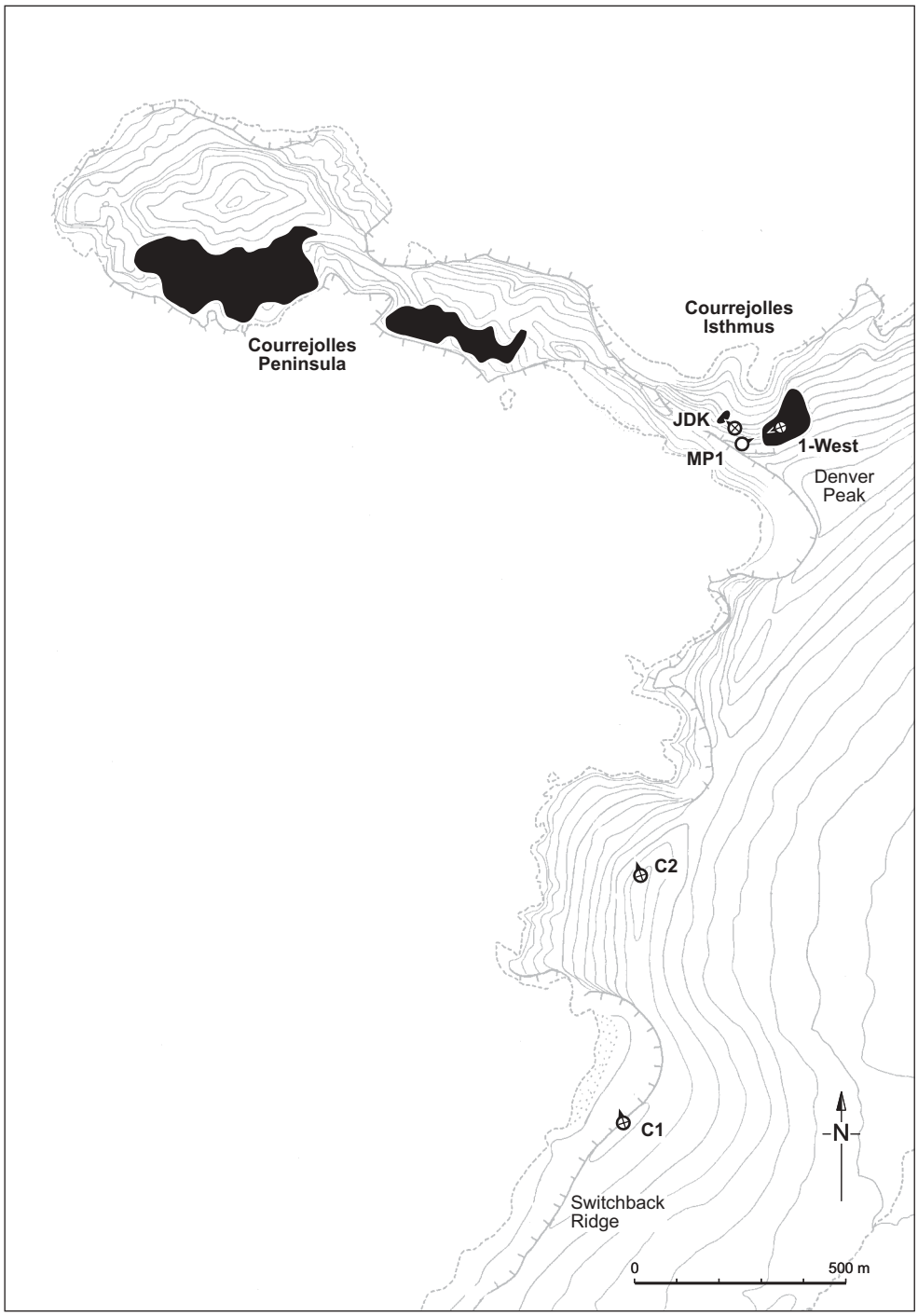


Figure 1. Location of mollymawk colonies on the north coast of Campbell Island. Boxed sections indicate the areas covered in Figs 2–4. Inset is the location of the island in the New Zealand subantarctic.

Stattersfield & Capper 2000). The third mollymawk species on Campbell Island is the biennially breeding grey-headed mollymawk (*T. chrysostoma*). The species also has a widespread subantarctic breeding distribution and a total population of about 142 000 breeding pairs (Tickell 2000), 92 300 of which bred each year (Gales 1998). At Campbell Island it was estimated there were 3000–10 000 pairs nesting in 1988 (Moore & Moffat 1990a) and 6400 in 1995 (P.J.M. in Gales 1998).

Most colonies on Campbell Island are mixed associations of Campbell and grey-headed mollymawks, with a few black-browed mollymawks, on steep slopes and ledges above sheer coastal cliffs (Bailey & Sorensen 1962; Robertson 1980; Moore & Moffat 1990a; Moore, Taylor & Amey 1997; Moore 1999). In 1987, photopoints were established at most of the major mollymawk colonies on the island (Moore & Moffat 1990a; Figs 2–4) to give good views of the colonies or to repeat views from historical photographs, particularly those taken during the 1940s. Comparison of old and recent photographs suggested that numbers of both species combined had declined since the 1940s by 38–57% (Moore & Moffat 1990a). In 1989–90 meteorological station staff on Campbell Island repeated some photographs, and over 1991–94, temporary and part-time

Figure 2. Locations of mollymawk colonies, photopoints (open circles, denoting marked viewpoint/s) and photoviews (crossed circles, denoting unmarked viewpoint/s) at Courrejolles Peninsula and Courrejolles Isthmus, Campbell Island.



Department of Conservation (DOC) staff conducted a wildlife monitoring programme, which including photography of mollymawk colonies.

Using photographs to estimate population trends has limitations, especially since the coverage of colonies on Campbell Island was incomplete, and there were long intervals between photographs. More importantly, the species could not be reliably distinguished in photographs. Therefore, a census of the colonies by ground counts was required to establish a population baseline for each species and to compare the results gained from photographs. Initial ground counts were conducted in 1992–94.

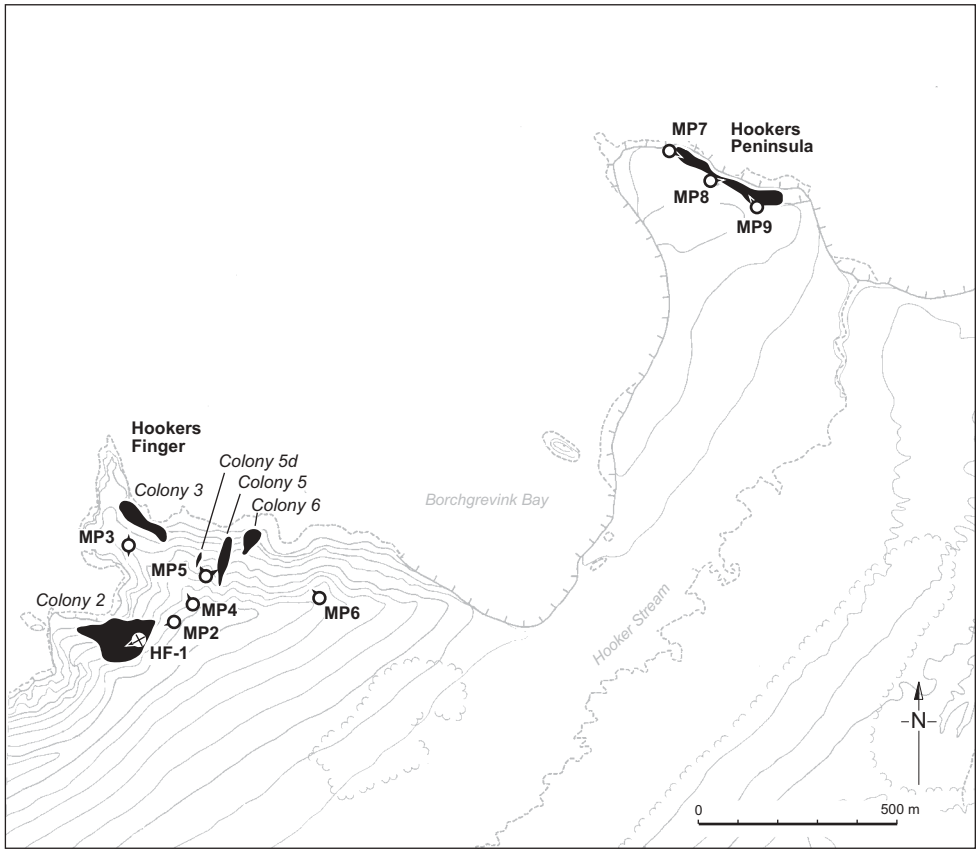


Figure 3. Locations of mollymawk colonies, photopoints (open circles, denoting marked viewpoint/s) and photoviews (crossed circles, denoting unmarked viewpoint/s) at Hookers Finger and Hookers Peninsula, Campbell Island.

Over 1995–97 the Science & Research Unit of DOC conducted a study of the mollymawks on Campbell Island. Its aims were to assess population size and trends of the mollymawk species using historical photograph comparisons and ground counts, and to standardise the counting methods used for future comparability. Preliminary analyses were presented in Waugh, Weimerskirch, Moore & Sagar (1999), concentrating on results from selected colonies. Colonies dominated by Campbell mollymawks declined between the 1970s and early 1980s, yet were stable or gradually increasing before and after that period. In contrast, the grey-headed mollymawk colonies apparently declined continuously from the 1940s to the 1990s (Waugh, Weimerskirch, Moore & Sagar 1999). More recently, methodologies for census (Moore 1999) and photographic analysis (Moore & Blezard 1999a) were published, and the large back-log of colony photographs (Moore & Blezard 1999b) and census results (Moore 2002) was collated and published. This report completes the report series and presents the analysis of data from all colonies and years.

2. Methods

Population estimates were made using counts of nests in photographs (photograph counts) and by counting nests at the colonies themselves (ground counts).

Throughout this report, 'year(s)' refer to mollymawk breeding seasons, which run from about September/October—when eggs are laid, to April/May—when chicks fledge. For example, 1987 refers to the 1987/88 season, hence a photograph taken in February 1988 is part of the 1987 season.

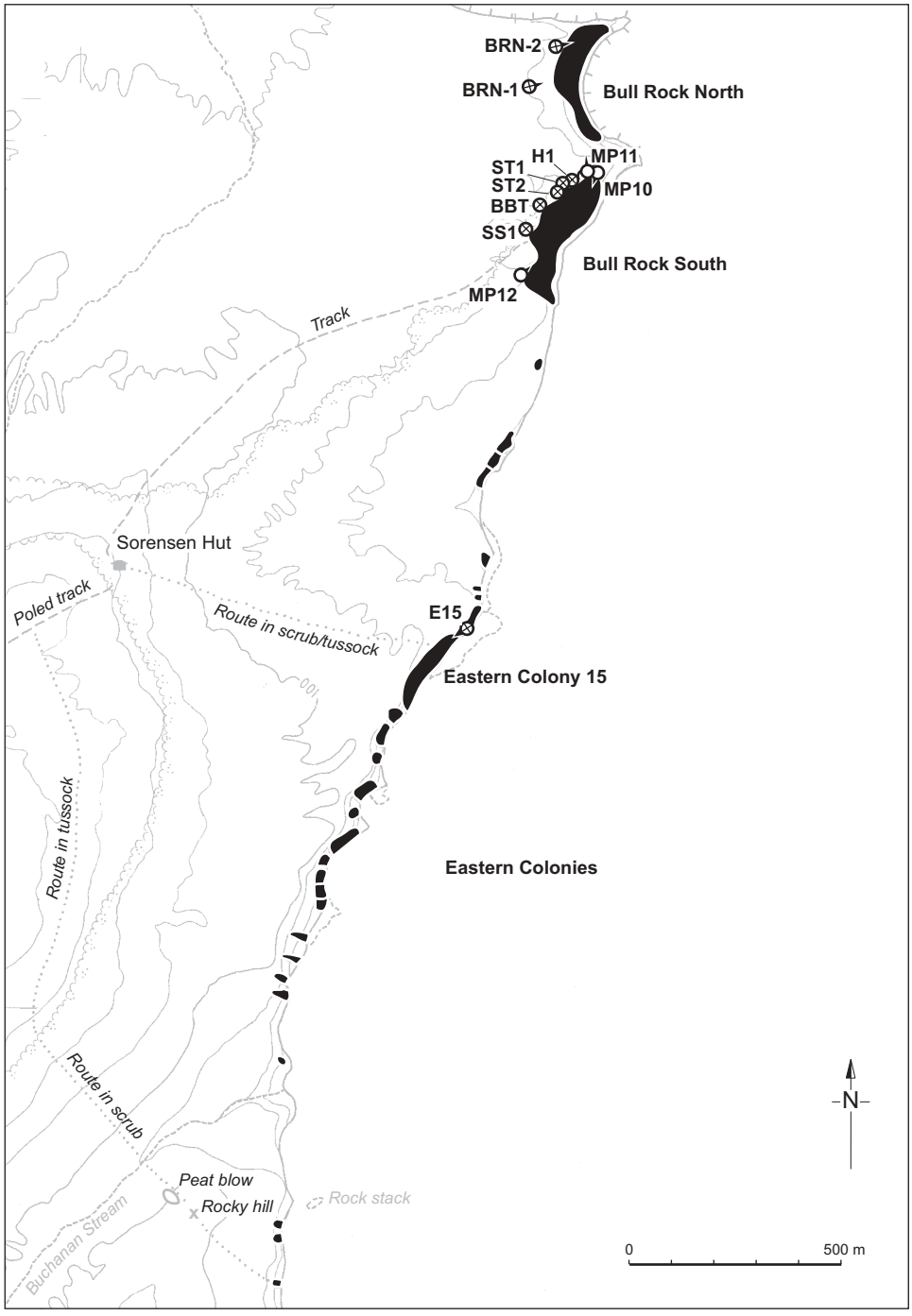


Figure 4. Locations of mollymawk colonies, photopoints (open circles, denoting marked viewpoint/s) and photoviews (crossed circles, denoting unmarked viewpoint/s) south of North Cape, Campbell Island.

2.1 PHOTOGRAPHS

Photographs were taken from the standard photopoints (marked viewpoints) as well as other photoviews (unmarked and variable viewpoints—often with few years of comparison). In 1987, Roger Moffat marked 12 photopoints near most of the major mollymawk colonies (Figs 2–4) to standardise comparisons and allow future trends to be assessed (Moore & Moffat 1990a; Moore & Blezard 1999a). These were positioned to give views of the colonies that were as complete as possible and, in five instances, repeated views seen in historical photographs taken by J. Sorensen in the 1940s. The large and inaccessible colonies of Courrejolles Peninsula were photographed from photoview C1 (or occasionally C2 in earlier years, Fig. 2) using telephoto lenses. Historical photographs of colonies, taken from similar photoviews over the years, were also compared. There were also whole or partial series of photographs taken from ships or helicopters which were useful for obtaining total counts of colonies and for comparison with ground counts. Details of photographers and example photographs are provided in Moore & Blezard (1999a, b).

Instructions for mollymawk photography were provided to staff stationed on the island, as part of a wildlife monitoring programme. Camera equipment varied, usually single-lens reflex 35 mm film format cameras (or 55 mm format), 35 mm and 50 mm lenses for standard photographs and 200 mm lens with 2× converter (or occasionally 500 mm lenses) for telephoto photographs of Courrejolles Peninsula. It was recommended that photographs be taken from 0900–1700 h (NZST) on one day by walking from Bull Rock South to Courrejolles Isthmus, and depending on the year, repeated monthly (September–May), or at key times of the breeding season (e.g. during early incubation or chick rearing). However, these criteria varied between years depending on when staff arrived on the island, the time available to them and weather conditions.

2.2 PHOTOGRAPH COUNTS

The majority of photographs were 205 × 297 mm (8 × 10 inch) black-and-white prints and nests and birds were counted by marking the photographs or overlays while viewing them under a binocular microscope (Moore & Blezard 1999a, b). Some colour slides were counted by projecting the image onto a white sheet. Colonies were divided into count zones, such as individual edges, or to delineate partial views. This allowed a subtotal of count zones representing a partial view to be compared across all years, whereas a larger view might only be comparable over a few years. These subtotals (T1–T76) are described in Moore & Blezard (1999a).

A bird on a nest was tallied as a 'nest', which is equivalent to the 'occupied nest' of ground counts (Moore 1999) or the 'apparently occupied nest' used in photograph counts of other seabirds (Bibby et al. 2000). Other birds were tallied separately as 'extras' if they were in the colony but not sitting on nests. 'Nests' and 'extras' were added together to arrive at a 'total birds' figure (Moore & Blezard 1999a). However, in this report, counts of 'nests' are the main unit of

analysis. Campbell and grey-headed mollymawks were not distinguishable in all photographs so photograph counts were combined totals of both species.

Several factors were known to influence the precision and accuracy of photograph counts. These are discussed in the following sections. Where possible, they were identified and minimised in the study.

2.3 PRECISION, ACCURACY AND ASSUMPTIONS OF PHOTOGRAPH COUNTS

Counts of birds give estimates of their population size which vary from the true mean as a result of normal variation (precision) or bias (accuracy). Counts with minimal levels of these statistical errors are said to be precise and accurate (Bibby et al. 2000).

Several problems are inherent in the use of photograph counts to estimate numbers and trends. Numbers of nests occupied by birds may vary naturally with the time of day, between days, seasonally or annually, and different counting methods or people may be less precise or accurate. Where possible, the potential biases were identified and minimised, as described below.

2.3.1 Non-nesting birds are confused with breeders

Mollymawks construct their nest bowls on top of 10–45-cm-high pillars of packed soil and grass (Marchant & Higgins 1990), and their nests are just out of pecking range from their neighbours. The resulting colonies are collections of regularly-spaced nest pillars and these allow nesting birds to be distinguished from non-nesting birds (breeding partners and idling birds). In distant views birds were visible in photographs as regularly-spaced white dots and the number of nests may have been over-estimated if non-nesting birds were counted as being on nests. This may have been accentuated if there were greater than normal numbers of non-breeders or breeding partners present in the colonies.

2.3.2 Quality of photographs, angle of view and distance to the colony may cause biases

The quality of photographs varied as a result of light and weather conditions, the lenses used for distant views, and printing exposure. More care was taken with photograph counts of lower quality photographs to correctly identify nests. If unusually high or low counts occurred, a second count was made of a better quality or larger print. Most photographs did not include the whole colony, but by subdividing the view into count sectors, areas in common could be compared across the years. Photograph counts of these areas provided an index for comparison (rather than an absolute count of the number of nests in the colony), since all photographs taken from standard positions should have similar biases.

2.3.3 Counter bias

In initial trial counts of nests in photographs (R. Moffat, P. Moore, G. Napp), it was noted that individuals differed in their counts, and usually tallied consistently fewer or more nests than other counters (counter bias). In this study, photograph counts were conducted by Peter Moore (1942–88 photographs), Alastair McLean (1942–94 photographs) and Reg Blezard (1942–97 photographs). Peter Moore provided training for the other counters and checked many of the marked overlays made by Reg Blezard for errors. Occasionally, if a count gave an unexpected result compared with that from a previous counter, a second count was made. To limit the effect of counter bias, all three counters counted most of the historical photographs (1942–86) and two counters counted several of the modern photographs (1987–94). The mean number of nests was used for graphing purposes and to compare changes in numbers between years. These replicate counts also provided a coefficient of variation (% standard deviation/mean) and an overall measure of precision for photograph counts. The positive or negative deviation from the mean number of nests was used to measure individual counter bias.

2.3.4 Number of occupied nests may vary with the time of day or between days

It was not known at what times of day the historical photographs were taken. Casual observations in 1987 suggested that there was less activity of breeding partners and non-breeders during the middle part of the day than in the evening. It was assumed, therefore, that counts of nests would be more precise if photographs were taken between 0900–1700 h (NZST); i.e. colonies would be less crowded with non-nesting birds (making counts of nests easier) and a small proportion of nests would be occupied by non-breeders. Limited comparisons were made of photographs taken on the same day, or two days apart, and further insight was gained from ground counts.

2.3.5 Numbers of nests vary with the stage of the breeding season

Mollymawks are relatively synchronous breeders, lay only one egg, and do not re-lay in the same year if the attempt fails. Therefore, it was assumed that counts of nests close to the peak laying period or during early incubation would provide an index to the number of breeding pairs present that season. The laying periods on Campbell Island were reported (Robertson 1980) as approximately 18 September to 8 October for Campbell mollymawks and 26 September to 9 October for grey-headed mollymawks. Consequently, by the second week in October, it was expected that the majority of birds of both species were incubating eggs, hence mid-October was chosen as the standard for photograph counts and ground counts. This assumption was checked in 1995–97: nest observations in September–October 1995 were used to clarify the peak laying period for each species, and ground counts in the second week of October were used to find what proportion of nests contained eggs.

In 1987, counts of nests in photographs at colonies dominated by Campbell mollymawks and grey-headed mollymawks showed a decrease in numbers similar to the pattern of breeding success of each species (Moore & Moffat

1990a). Because photographs were taken at variable times of the breeding season over the years (mid-October in 1995–97, September–December in the 1980s–90s and October–February in the 1940s–70s), most photograph counts would underestimate the breeding population. To further study the seasonal trend in nest numbers and provide data for adjusting photograph counts to mid-October values, 6–8 photographs were taken at each photopoint from September to April in 1991 and 1992, and a lesser number of photographs in each of the following 5 years. Breeding success was monitored at Bull Rock South and ground counts at other areas for comparison with photograph counts.

Photograph counts for each photopoint were converted to a percentage of the mid-October count for that year. Regression lines were fitted for September–December (incubation period) and January–April (chick-rearing period) for each photopoint (see Table A1.1 in Appendix 1) and for the combined data from colonies dominated by grey-headed or Campbell mollymawks (see Figs A1.1 and A1.2, Table A1.1 in Appendix 1). These regression equations were used to convert the photograph counts to mid-October estimates if required. Counts from the Courrejolles Peninsula were converted to mid-October values using the general regression line for colonies dominated by Campbell mollymawks (see Fig. A1.2, Table A1.1).

2.3.6 Annual variation

Data from consecutive years such as 1995–97 allow for short-term fluctuations in numbers to be observed and averages taken, yet historical photographs from single years may provide spurious results if colony attendance varied between years. However, the vegetation patterns at the colony boundary and areas of empty nests can give a guide to the state of the colony in the years before a photograph was taken.

2.3.7 Species variation

Colonies were mixed-species assemblages and dominated by Campbell mollymawks (annual breeders) or grey-headed mollymawks (biennial breeders) to varying degrees. It was assumed that population trends at the colonies would reflect the trends of the dominant species. At most colony assemblages (seven areas), one or other species was more dominant (73–95%) and, presumably, the overall changes in nest numbers over the years reflected the population trends of the dominant species. At colonies where the species proportions were fairly even (3 areas: Hookers Finger Colony 2, Hookers Peninsula, and Courrejolles Peninsula, where 58–67% of the colonies were composed of grey-headed mollymawk nests) the species' population trends might be more likely to counteract each other.

2.4 GROUND COUNTS

Ground counts of mollymawk colonies on Campbell Island were conducted during the egg laying or incubation stage in 1992–97. As for photograph counts, the main counting unit was the occupied nest, and all subsequent references to

'nests' refer to this. Other birds were tallied separately as 'extras' if they were in the colony but not sitting on nests. 'Nests' and 'extras' were added together to arrive at a 'total birds' figure (Moore 1999, 2002). However, in this report counts of 'nests' are the main unit of analysis. Nests of Campbell and grey-headed mollymawks were tallied separately, but black-browed mollymawks were included in the Campbell mollymawk totals. The reason for this was that using the black iris as the main distinguishing feature of black-browed mollymawks was not always reliable (20% of dark-eyed birds were found to be Campbell mollymawks from mitochondrial DNA analysis; Moore, Burg et al. 2001). Also, they were rare (30–100 individuals), easily overlooked amongst the very similar and numerous Campbell mollymawks, and most had Campbell mollymawk partners (Moore, Taylor & Amey 1997; Moore, Burg et al. 2001).

Most colonies were accessible, and ground counts of these were made during the periods 24–27 September 1992, 25 October 1993 (a partial census) and 19 September–5 October 1994. Accessible colony groupings are at the Courrejolles Isthmus, Hookers Finger, Hookers Peninsula, Bull Rock North, Bull Rock South and Eastern Colonies (Figs 1–4). General counting instructions were provided to staff. They usually tallied occupied nests while walking along the colony ledges (c. 66%–100% of nests counted each year), supplemented by counts of ledges or whole colonies from viewpoints (J. Amey, J. Henderson, pers. comm.).

Further ground counts were conducted on 9–22 October 1995, 7–16 October 1996 and 8–15 October 1997. This was at, or close to, the end of the laying period for both species. Five count types were used: 'nest visits', where all birds occupying nests (with and without eggs) were counted and marked with powder spray to reduce the chance of over-counting or under-counting; 'ledge' counts, where tallies of nests were made while walking on the ledge; 'view down', a count by eye from the next ledge up; 'binocular view down', a count by eye from a vantage point such as a cliff above a colony; and 'binocular view across', from a vantage point such as a headland (Moore 1999).

A sixth method, 'telescope view', was used in combination with photograph counts of the inaccessible Courrejolles Peninsula (Fig. 2). Telephoto pictures were taken of the colonies in October 1992, 25 October 1993, 29 October 1995, 26 October 1996 and 18 October 1997 and photograph counts were made to estimate the total number of nests. In 1992 and 1995, the colonies were viewed by telescope and the areas predominantly composed of grey-headed mollymawks were marked on photographs so that the two species could be tallied separately. On 18 October 1996, and 18–19 October 1997, numbers of nests of grey-headed mollymawks were counted using 'telescope views'. Campbell mollymawk numbers were estimated as the difference between the total photograph counts and the telescope count of grey-headed mollymawks.

The six different count methods were based on a mixture of perceived reliability, convenience (e.g. the time available), practicability (e.g. whether it was safe or possible to visit all ledges, or if viewpoints gave unobstructed views) and previous methods used (e.g. binocular views across to Bull Rock North). It was also hoped to find the most reliable and time-effective combination of methods for each colony. The main counting method used in 1995 was the ledge count, and many other colony ledges were counted from above using views down and binocular views down (Table 1). While ledge

TABLE 1. PROPORTION OF NESTS OF GREY-HEADED AND CAMPBELL MOLLYMAWKS COUNTED BY DIFFERENT METHODS DURING GROUND COUNTS OF ACCESSIBLE COLONIES IN 1992–97 (ESTIMATED FOR 1992–94).

	PERCENTAGE COUNTED BY EACH METHOD PER YEAR											
	GREY-HEADED MOLLYMAWK						CAMPBELL MOLLYMAWK					
YEAR	1992	1993	1994	1995	1996	1997	1992	1993	1994	1995	1996	1997
Nest visit				27.7	88.3	89.2				15.9	73.8	76.3
Ledge	c. 68.5	c. 100	c. 66.3	43.8	4.5	1.6	c. 79.6	c. 100	c. 79.0	58.7	13.2	6.3
View down				2.1	0.5	2.0				12.2	0.8	1.6
Binocular view down	c. 16.5		c. 17.3	11.2	3.2	3.5	c. 2.6		c. 2.9	5.3	5.9	6.0
Binocular view across	c. 15		c. 16.4	4.5	3.5	3.7	c. 17.8		c. 18.1	7.9	6.2	9.7

counts were straightforward on narrow ledges, they were difficult to conduct in large areas of nests with few reference points. In these situations nest visit counts were more suitable, as the marking of birds gave a simple guide to which had been counted and which had not.

2.5 PRECISION, ACCURACY, AND ASSUMPTIONS OF GROUND COUNTS

Several problems are inherent in the use of ground counts to estimate numbers and trends: some of them occur in common with photograph counts, and others are unique to ground counts. Where possible, the potential biases were identified and minimised, as described below.

2.5.1 Method biases

In 1996 it was realised that some of the views down and binocular views down in the previous year had missed small areas of obscured nests, and hence that these methods would tend to underestimate the number of nests. On the other hand, all tallies of nests probably over-represent the number of pairs that are breeding, since non-breeders sit on unused nest bowls. To minimise these problems, the 'nest visit' count method was used as much as possible in 1996 and 1997 (Table 1) with the aim of increasing reliability and to determine the proportions of nests containing eggs. Drawbacks to the method included the extra time required and the greater disturbance to nesting and non-nesting birds.

To test for method bias, a limited number of paired comparisons were made in 1995–97 between nest visits (the most intensive count method) and other count types. These included: ledge counts (N = 12); views down (N = 13); binocular views down (N = 11); and binocular views across (N = 16).

2.5.2 Precision and counter bias

Some counts were replicated to measure count precision and counter bias. Between one and three observers conducted 1–4 consecutive counts for binocular views across (N = 40), views down (N = 2) and binocular views down (N = 12). Ledge counts were replicated in 1996 by each of three observers

counting sets of 2–5 consecutive counts of the same ledge on the same day (N = 4). Nest visit count variation was tested in 1997 by each of three observers counting the same sector once on the same day (N = 11). Telescope views were tested for count variation in 1997 by two observers counting the same sectors (N = 10). Each set of counts at a colony sector on the same day by the same observer, or 2–3 observers, using the same method, was considered as one replication and the coefficient of variation calculated. The mean CV gave a measure of precision for each count method. Those counts that were replicated by 2–3 people were used to measure potential counter bias.

2.5.3 Variation by day or time of day

One test of daily variability came from ground counts of two adjacent areas of Bull Rock South, by one observer counting 'nests' (with and without eggs) and 'extras' once on 30 October 1996, and a second observer counting 'nests' (without eggs) and 'extras' five times between 0845 h and 1645 h on 1 November 1996.

2.5.4 Time of breeding season

In 1995–97, repeat counts of selected colony sectors were made at different times of the season so that ground counts from 1992–94 could be converted to mid-October values. About 24 ledges of varying size from 6 colonies (Moore 1999) were counted 3–4 times in 1995, 4 times in 1996 and twice in 1997 between late September or mid-October and mid-December. Regression lines for this data were fitted for grey-headed mollymawk- and Campbell mollymawk-dominated colonies (Figs A1.3–A1.4, Appendix 1).

3. Results

3.1 PRECISION, ACCURACY AND ASSUMPTIONS OF PHOTOGRAPH COUNTS

The laying schedule was confirmed in 1995, as 34% of Campbell mollymawk eggs being laid between 18 and 26 September and the remaining 66% by 8 October (G. Murphy, S. Waugh, pers. comm.). One grey-headed mollymawk egg was seen on 25 September 1995, 94% of eggs were laid by 9 October and the remainder by 17 October (G. Murphy, S. Waugh, pers. comm.). Hence, being near the beginning of the incubation period for both species, mid-October (approximately 8–21 October), was an appropriate time to conduct photograph counts of nests, or as a standard for conversion of counts of photographs taken later in the season. This was further supported by ground counts conducted during the second week of October in 1995–97 that found, on average, 79.5% of grey-headed mollymawk nests and 85.2% of Campbell mollymawk nests contained eggs. The remainder of nests were occupied by birds that were yet to lay (up to 6% of grey-headed mollymawk nests), had already lost their egg, or were non-breeders.

TABLE 2. COUNTER BIAS, EXPRESSED AS PERCENTAGE DEVIATION FROM THE MEAN NUMBER OF NESTS IN PHOTOGRAPH COUNTS OF MOLLYMAWK COLONIES ON CAMPBELL ISLAND.

	COUNTER BIAS*							
COUNTER (initials)	P.M.		A.M.		R.B.		N	ANOVA
	MEAN	S.D.	MEAN	S.D.	MEAN	S.D.		
All 3 counters counting the same photographs	-5.0	3.7	5.7	4.0	-0.7	4.9	13	$F_{2, 36} = 21.1, P < 0.001$
2 counters counting the same photographs	-5.1	5.0	5.1	5.0			21	$F_{1, 40} = 44.1, P < 0.001$
	-8.3				8.3		1	
			2.2	5.4	-2.2	5.4	56	$F_{1, 110} = 18.1, P < 0.001$
All comparisons	-5.2	4.4	3.4	5.3	-1.7	5.4	195	$F_{2, 190} = 37.5, P < 0.001$

* Percentage deviation from mean number of nests.

The mean CV for replicated photo counts (N = 91) was 6.6% ± 5.4% (range 0–28) Two outliers > 40% were omitted from analyses as these were probably gross recording errors. There was significant variation between counters, for all comparisons of two or three counters, and for all comparisons combined (Table 2). This was because each person tended to count higher or lower than the mean number of nests, but on average, they were all within 6% of the mean count (Table 2). Some photographs that were suspected of providing an anomalous count were repeated by the same observer, using the same or better print; the mean CV for these replicated photo counts was 6.2% ± 4.4% (range 1%–13%, N = 11).

Table 3 shows that variability in the number of nests in two photographs taken on the same day (CV = 4.9%) or similar day (CV = 6.2%) was similar to the variation in replicated counts of the same photograph. In other words, in this example, the change in number of nests (the natural variation) was probably minimal and smaller than the precision of the estimate (the counting variation). Further potential for variation in the number of nests counted in photographs, as a result of differing numbers of non-breeders occupying empty nests, can be inferred from ground counts (see Section 3.3).

Counts of nests in photographs at colonies dominated by Campbell mollymawks or grey-headed mollymawks showed nest numbers decreased during the breeding season at rates similar to the pattern of breeding success for those species, for example in 1987 and 1991 (Figs A2.1–A2.4, Appendix 2); and

TABLE 3. EXAMPLES OF PHOTOGRAPH COUNTS OF NESTS, NON-NESTING BIRDS (EXTRAS), AND TOTAL BIRDS AT MOLLYMAWK COLONIES ON CAMPBELL ISLAND, FROM PHOTOGRAPHS TAKEN ON THE SAME DAY AND 2 DAYS APART.

COLONY	PHOTO-POINT	COLONY SECTORS	DATE	TIME (NZST)	NESTS (N)	EXTRAS (N)	TOTAL (N)
Hookers Finger 2	MP2	T13	29 October 1995	1000 h	305	7	312
				1300 h	327	12	339
Bull Rock North	MP11	T41	10 October 1996	0900 h	2815	49	2864
			12 October 1996	1030 h	3071	11	3082

also in 1992 and 1993 (P. Moore, unpubl. data). Similarly, photograph counts (nests and total birds) and ground counts (eggs, nests and total birds) showed similar decreasing trends in October–November 1995 (Figs A2.5–A2.7), although photograph counts appeared to underestimate the proportion of 'extra' birds in the counts of 'total birds'. The main exception to the downward trend in photograph counts during the breeding season occurred in 1996 when photograph counts of Campbell mollymawk areas in November–December overestimated the number of nests (Fig. A2.8, Appendix 2), perhaps a result of confusion between 'nests' and 'extras'. Relatively high counts tended to occur in December (hatching stage) or January (early chick rearing), possibly because large numbers of breeding partners and non-breeders were present in the colonies and these were counted as nesting birds. This seasonal variability, as well as differences between colonies, is reflected in the spread of data points in Figs A1.1–A1.2 (Appendix 1), and would have influenced, to some extent, the regression lines (Table A1.1) used to calculate the numbers of nests in mid-October. However, most counts required minor adjustment, particularly in the 1990s, when most photographs were taken within 3 days of 15 October. The remainder of the historical photographs were generally taken between October and December, with a few in January–February.

3.2 PHOTOGRAPH COUNTS

Photograph counts for accessible colonies are presented below, following the order of the standard photopoint series MP1–12 (a clockwise progression around the north of the island, Figs 1–4). Each section also includes additional photoview information from the area. Results from the inaccessible colonies of the Courrejolles Peninsula are then presented. Species composition data from ground counts are also provided to set the scene for each colony. The mean counts of nests in photographs and percentage changes between each historical period and 1995–97 are summarised in Tables 4 and 5. Trends in the number of nests are plotted in Figs 5–17, and annual rates of change in the text were calculated from the regression equations (Figs 5–17).

3.2.1 Courrejolles Isthmus

Courrejolles Isthmus is a small accessible colony at the inland end of the Courrejolles Peninsula (Figs 1 and 2). (Because Courrejolles Isthmus is an accessible colony, it is treated separately from the inaccessible colonies of the Courrejolles Peninsula). Virtually all the birds identifiable to species in the 1940s and 1990s photographs were grey-headed mollymawks and this species occupied 79% of nests at the colony during ground counts in 1995–97.

Photopoint MP1

MP1 is the standard viewpoint of Courrejolles Isthmus (Fig. 2).

A partial view of the colony (count zone subtotal T9) showed a similar occupancy in 1942 and 1945 with mid-October estimates of 504 and 562 nests respectively.

The wider view in the 1945 photograph (T6) was used for comparison with later photographs. The number of nests declined by 88.5% between 1945 and

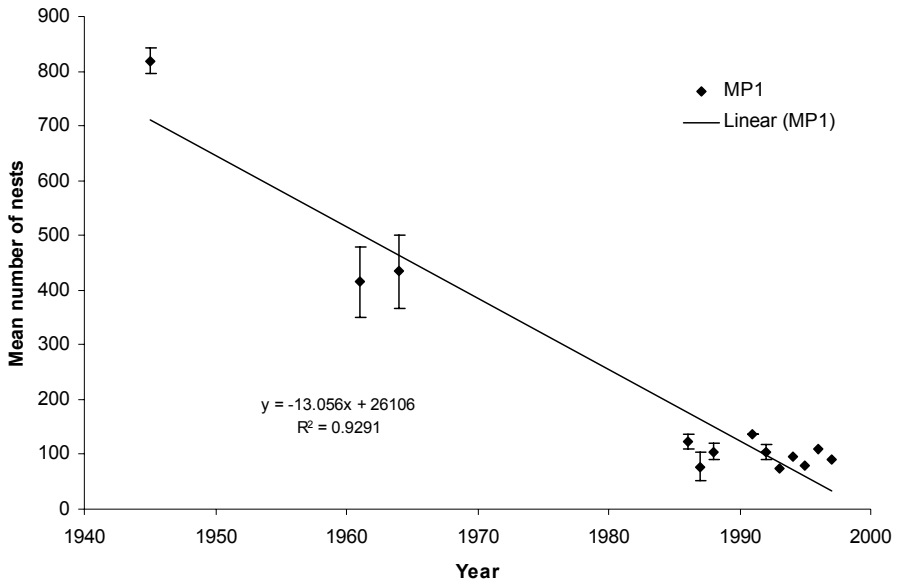


Figure 5. Trends in the number of nests at Courrejolles Isthmus mollymawk colony (composed mainly of grey-headed mollymawks), counted from photographs taken from photopoint MP1, 1945–97. Two points are shown for the 1960s as it is not certain if photographs were taken in 1961 or 1964. All photographs were taken between late September and late November and counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

TABLE 4. ESTIMATED POPULATION CHANGE AT COLONIES DOMINATED BY GREY-HEADED MOLLYMAWKS BY COMPARING MEAN NUMBER OF NESTS IN PHOTOGRAPH COUNTS FROM DIFFERENT PERIODS (1940S TO 1990–94) WITH 1995–99.

AREA	PHOTO-POINT OR PHOTO-VIEW	COUNT ZONE SUB-TOTAL†	MEAN NUMBER OF NESTS IN MID-OCTOBER AND THE PERCENTAGE CHANGE TO 1995–97*							
			1940s	1950s	1960s	1970s	1980–84	1985–89	1990–94	1995–97
Courre-	MP1	T6	819		425			105	103	94
jolles	1-West	T59	276			56		17		1
Isthmus	JDK	T60	313					70	97	72
	MP1, 1-West, JDK	T6, T59, T60	1408					192		167
	Change (%)		– 88.1					– 13.0		
Hookers	HF-1	T61	949							205
Finger	MP2	T13	1678					400	355	352
Colonies	MP3a	T17	2586				581	532	419	450
2, 3	MP4	T24	698					162	164	144
	MP3a, MP4	T17, T24	3284					694	583	594
	Change (%)		– 81.9					– 14.4	+1.9	
Hookers	Boat/air					1417	1289	1267	1203	
Peninsula	MP7‡	T27						381	478	453
	MP8	T29						126	100	78
	MP9	T31						239	231	187
	MP7, MP8, MP9	T27, T29, T31						746	809	718
	Change (%)							– 3.8	– 11.2	

* Counts were converted to mid-October if necessary using the regression lines in Table A1.1 (Appendix 1), then averaged for the period. Figures include means of multiple counts of individual photographs (e.g. most of the historical photographs, 1940s–70s) and single or multiple counts of photographs in other years (e.g. 1980s–90s).

† Count zones of colonies were combined in a subtotal that was comparable in all years for the photopoint or photoview (Moore & Blezard 1999a, b).

‡ MP7 views a sector of the colony which is dominated by Campbell mollymawks.

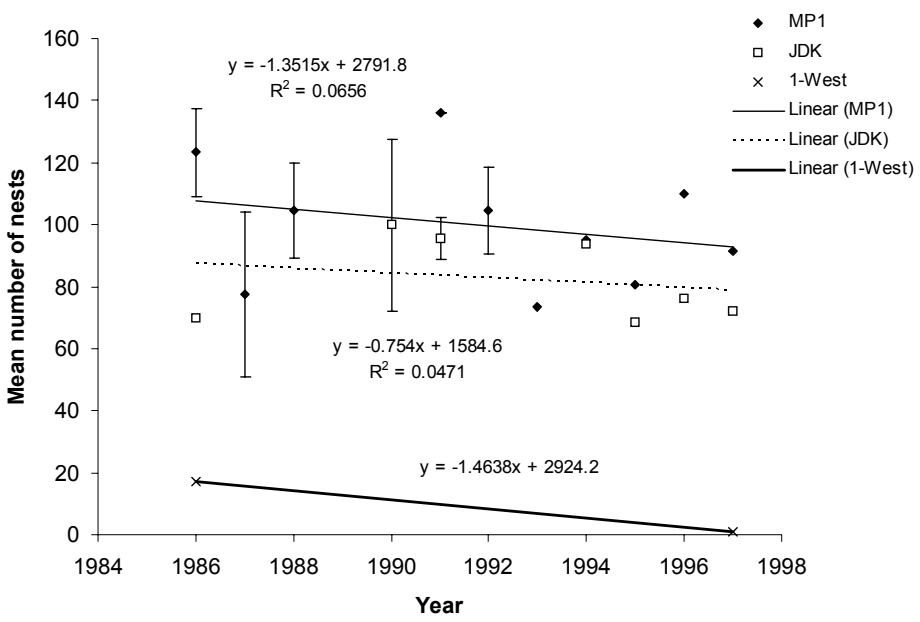


Figure 6. Trends in the number of nests at Courrejolles Isthmus mollymawk colony (composed mainly of grey-headed mollymawks), counted from photographs taken from photopoint MP1, and photoviews JDK and 1-West, which view different parts of the colony, 1986–97. All photographs were taken between late September and late November and counts of nests were converted to mid-October with regression lines in Table A1.1 Points are means ± SD of multiple counts, or single counts.

1995–97 (Table 4), and the area occupied also substantially decreased. Assuming a constant rate of change shown by the regression line in Fig. 5, this represents a 1.8% annual rate of decline (relative to 1945 numbers). There was a greater proportional decrease in the first two decades (48%, at a rate of 2.7% p.a.) than later. By the 1980s–90s the rate had slowed to 1.2% p.a. (as shown by the regression line in Fig. 6), although the number of nests fluctuated between 70 and 140. (Fig. 6, Table 4).

Photoview 1-West

A different part of Courrejolles Isthmus was viewed from 1-West (Fig. 2) and photographs were taken sporadically over a 55-year period. The numbers of nests declined by 99.6% down to one nest in 1997 (Table 4, Figs 6–7), representing a decline of 2.1% p.a. (relative to 1943 numbers, calculated from the regression equation in Fig. 6). As with MP1, the proportional decrease was greatest in the first three decades (79.7%, Table 4, Fig. 7).

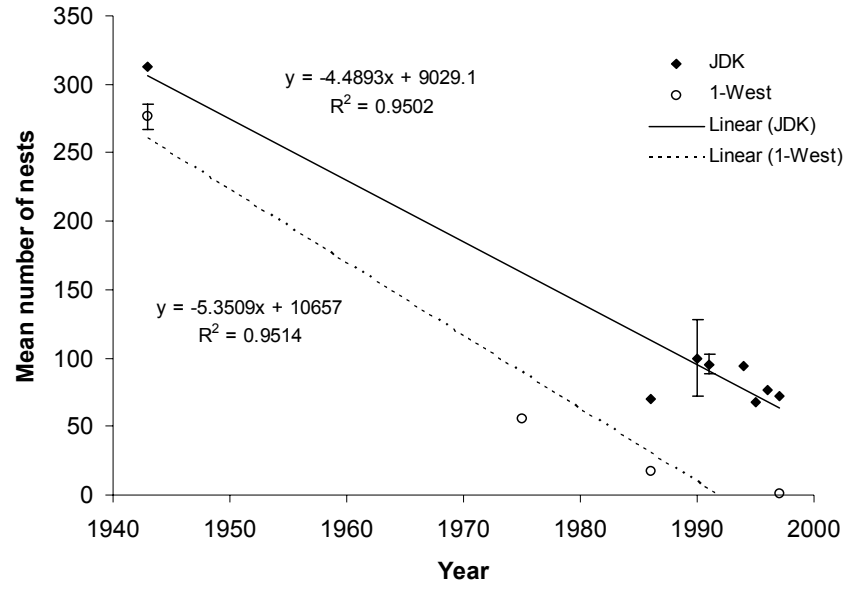


Figure 7. Trends in the number of nests at Courrejolles Isthmus mollymawk colony (composed mainly of grey-headed mollymawks), counted from photographs taken from photoviews 1-West and JDK , which view different parts of the colony, 1943–97. All photographs were taken between late September and mid-December and counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

Photoview JDK

JDK sub-colony of Courrejolles Isthmus (Fig. 2) had a continuous cover of nesting birds extending beyond the bounds of a 1943 photograph, but only a remnant cluster of birds remained in the 1980s–90s, indicating an overall decline of at least 77% (Table 4), at a rate of 1.5% p.a. (Fig. 7). Several repeat photographs were made in the 1980s–90s and although numbers of nests were variable between years, mainly because of a low count in 1986, the trend was still downward by 0.85% p.a. (Fig. 6).

A composite total of 1408 nests from MP1, 1-West and JDK viewpoints in the 1940s, and 167 in 1995–97, showed there had been an overall decline in numbers at Courrejolles Isthmus of 88.1% (Table 4).

3.2.2 Hookers Finger Colony 2

Four colonies are found at Hookers Finger: Colonies 2, 3, 5 and 6 (Fig. 3). (Hookers Finger colonies were named arbitrarily after their closest photopoint; Colony 3 is viewed from photopoints 3 and 4, hence there is no Colony 4). Hookers Finger Colony 2 is on the south-west side of the Hookers Finger ridge (Fig. 3). All the foreground birds in a close-up photograph of the colony (photoview HF-1) during the 1940s appeared to be grey-headed mollymawks and this species occupied 65% of nests during ground counts in 1995–97.

Three photographs from different viewpoints were taken of Colony 2 in 1942 and 1943 and these were re-photographed in the 1980s–90s.

Photopoint MP2

An incomplete view of Colony 2 from the ridge adjacent to the colony showed a 79% decrease in the number of nests between 1942 and 1995–97 (Table 4), a decrease of 1.5% p.a. (Fig. 8). Large tussocks are visible in recent photos in areas that were formerly occupied by nests. Although fluctuating annually in the 1980s–90s, the trend in number of nests continued downwards (1.7% p.a., Fig. 9).

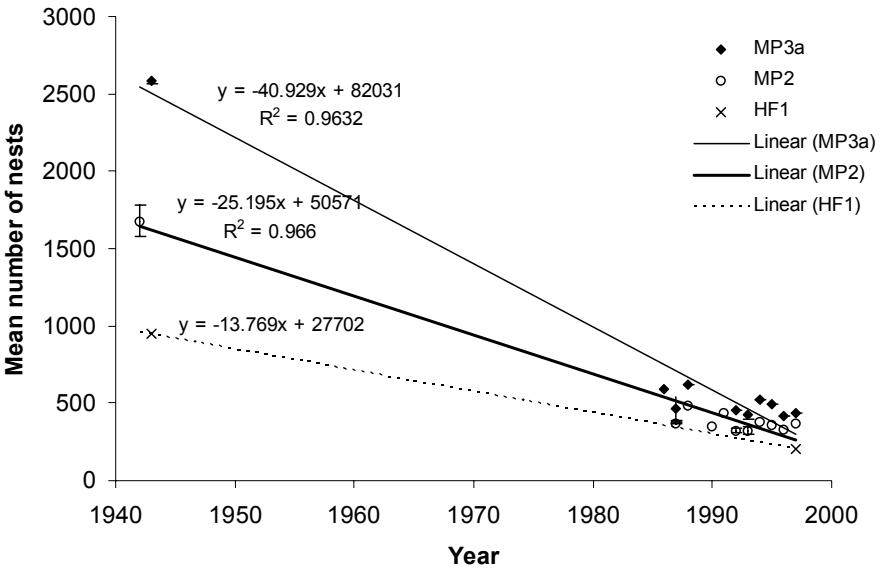


Figure 8. Trends in the number of nests at Hookers Finger Colony 2 (composed mainly of grey-headed mollymawks), counted from photographs taken from photopoints MP2 and MP3a and photoview HF-1, 1942–97. All photographs were taken between late September and mid-November, except for 1986, which was taken in January. Counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

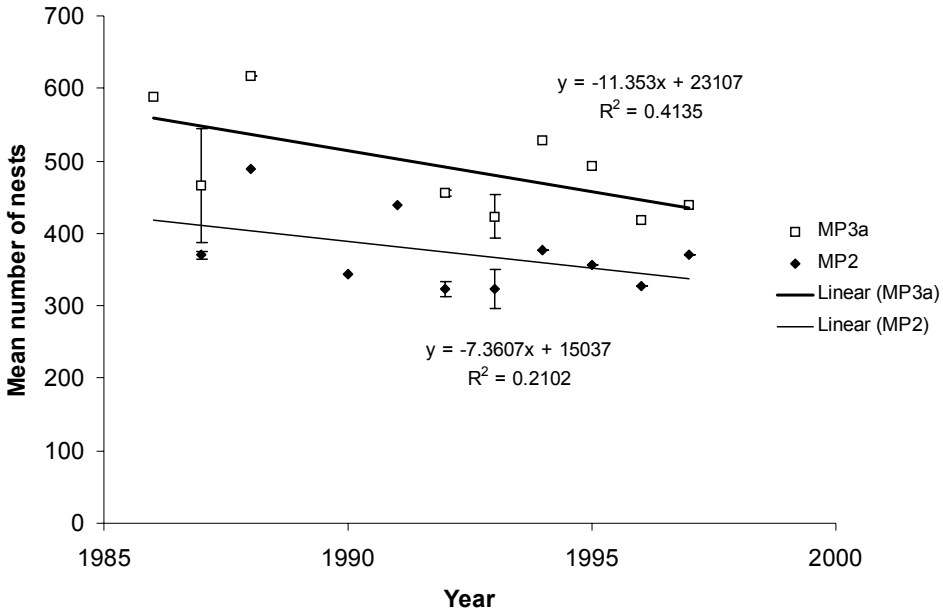


Figure 9. Trends in the number of nests at Hookers Finger Colony 2 (composed mainly of grey-headed mollymawks), counted from photographs taken from photopoints MP2 and MP3a, 1986–97. All photographs were taken between late September and mid-November, except for 1986 which was taken in January. Counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

Photopoint MP3

A viewpoint (MP3a) further down the Hookers Finger ridge, gave an almost complete view of Colony 2, albeit looking slightly uphill. There was an 82.6% decrease in the numbers of nests between 1943 and 1995–97 (Table 4, Fig. 8). The 1943 photograph showed an almost continuous cover of nests, but the nesting area was a fragmented patchwork in the 1980s, and further sub-colonies and peripheral nesting areas disappeared in the 1990s. Assuming a continuous decline represented by the regression line in Fig. 8, this equates to a decline of 1.6% p.a. Counts of nests also fluctuated in the 1980s–90s, in a similar pattern to MP2, and with an overall downward trend (1.9% p.a., Fig. 9).

Photoview HF-1

A closer, more oblique view, of a central part of the colony showed a 78.4% decrease in the number of nests between 1943 and 1997 (Table 4; 1.5% p.a., Fig. 8).

3.2.3 Hookers Finger Colony 3

Colony 3, near the end of the Hookers Finger ridge (Fig. 3), is predominantly composed of grey-headed mollymawks, which occupied 80% of nests during ground counts in 1995–97.

Photopoint MP4

A view of Colony 3 from near the top of the Hookers Finger ridge showed a decrease of 79.4% in the number of nests between 1942 and 1995–97 (Table 4), or a 1.5% p.a. decline (Fig. 10). During the 1980s–90s nest numbers fluctuated, but with a downward trend (1.9% p.a., Fig. 11).

Photopoint MP3

A closer but more restricted view (MP3b) of Colony 3 showed a similar pattern of fluctuations as MP4, and a decreasing trend in nest numbers, in the 1980s–90s (2.9% p.a., Fig. 11).

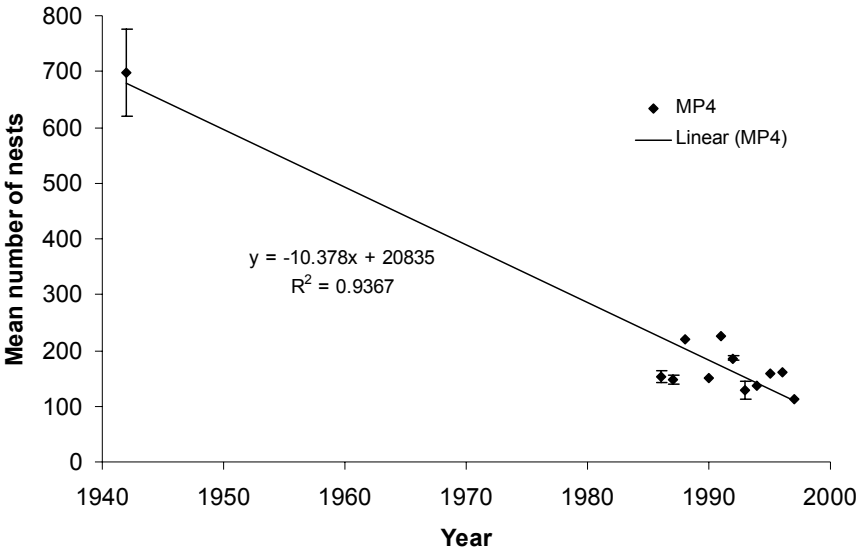


Figure 10. Trends in the number of nests at Hookers Finger Colony 3 (composed mainly of grey-headed mollymawks), counted from photographs taken from photopoint MP4, 1942–97. All photographs were taken between late September and early November, except for 1986 which was taken in January. Counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

3.2.4 Hookers Finger Colony 5

Colony 5, on the eastern side of Hookers Finger ridge (Fig. 3), is composed mainly of Campbell mollymawks (84% of nests during ground counts in 1995–97). A small subcolony (5d) in a neighbouring gully was also mainly occupied by Campbell mollymawks (68% of nests).

Photopoint MP5

Counts of photographs of Colony 5 taken in the 1980s–90s from MP5 showed a fluctuating trend in the number of nests (Table 5), decreasing at a rate of 1.3% p.a. (Fig. 12).

Photopoint MP5d

The number of nests at subcolony 5d also decreased steadily throughout the 1980s–90s in a similar manner to the larger colony (Table 5), falling at a rate of 3.5% p.a. (Fig. 12).

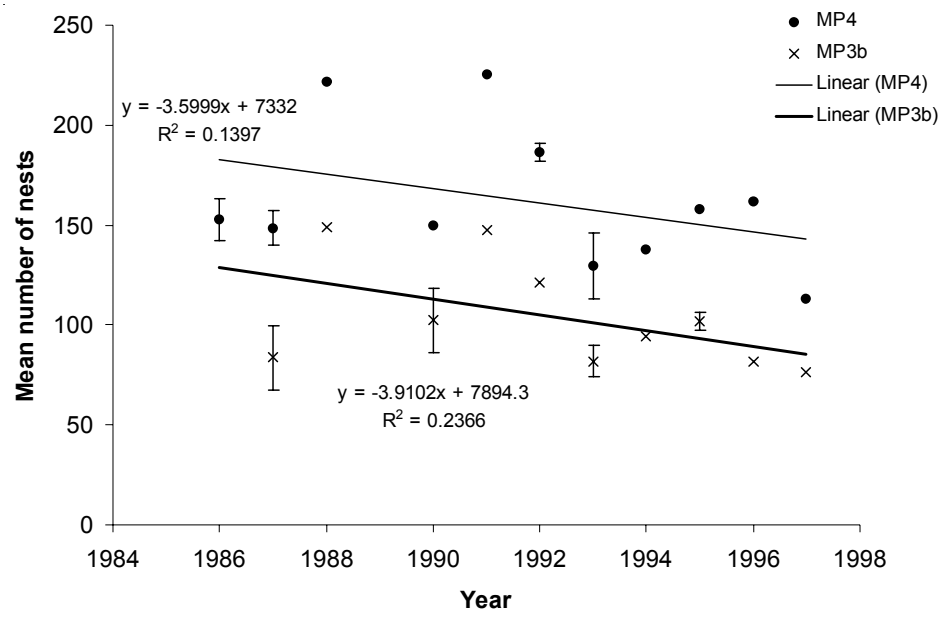


Figure 11. Trends in the number of nests at Hookers Finger Colony 3 (composed mainly of grey-headed mollymawks), counted from photographs taken from photopoints MP3b and MP4, 1986–97. All photographs were taken between late September and early November, except for 1986 which was taken in January. Counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

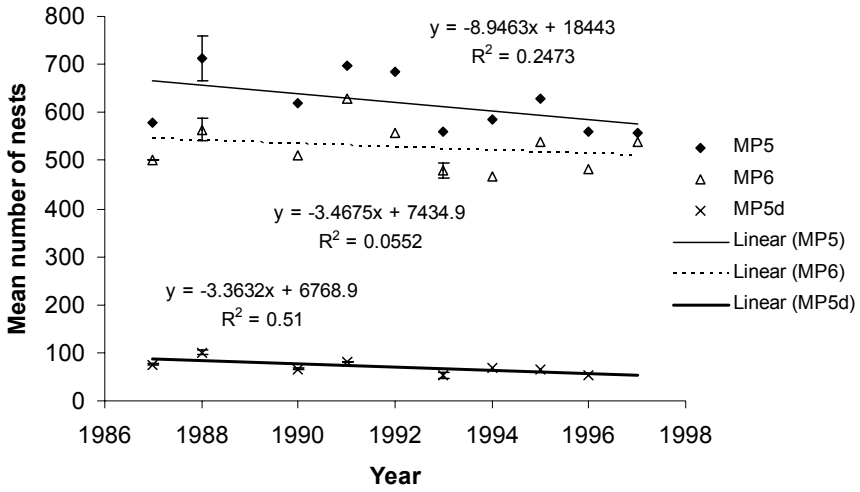


Figure 12. Trends in the number of nests at Hookers Finger Colonies 5 and 6 (composed mainly of Campbell mollymawks), counted from photographs taken from photopoints MP5, 5d and 6, 1987–97. All photographs were taken between late September and mid-November. Counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

3.2.5 Hookers Finger Colony 6

Hookers Finger Colony 6 is northeast of Colony 5 (Fig. 3), and 73% of its nests were occupied by Campbell mollymawks during ground counts in 1995–97.

Photopoint MP6

The number of nests at Colony 6 fluctuated in a similar pattern to neighbouring Colony 5, and although the trend was more stable, there was a slight decline of 0.6% p.a. (Table 5, Fig. 12).

3.2.6 Hookers Peninsula

The Hookers Peninsula colony is a scattered nesting area and, overall, grey-headed mollymawks were slightly more numerous, occupying 58% of nests during ground counts in 1995–97. At the western sub-colony, Campbell mollymawks (59% of nests) were more numerous, whereas the eastern sub-colonies were dominated by grey-headed mollymawks (73% of nests).

Photographs taken of the Hookers Peninsula colony from sea in 1975 and helicopter in 1985, 1989, and 1990, showed a decrease of 15.1% in the number of nests (Table 4).

Hookers Peninsula is viewed from three photopoints.

Photopoint MP7

The western sub-colony showed wide fluctuations in nest numbers during 1980s–90s, particularly during the first half of the decade. Overall, there was an increasing trend (of 1.2% p.a.; Table 4, Fig. 13). However, this was influenced by the low count in 1987 (Fig. 13). If that point is removed, the remaining data have a slight decreasing trend, particularly because of an apparent decline through the 1990s (Table 4, Fig. 13).

Photopoint MP8

Peripheral eastern sub-colonies showed a similar, though attenuated, pattern of fluctuations, but a steady decline (of 4.1% p.a.) in the number of nests during the 1980s–90s (Table 4, Fig. 13). The decrease resulted in some nesting areas no longer being used by the end of the period.

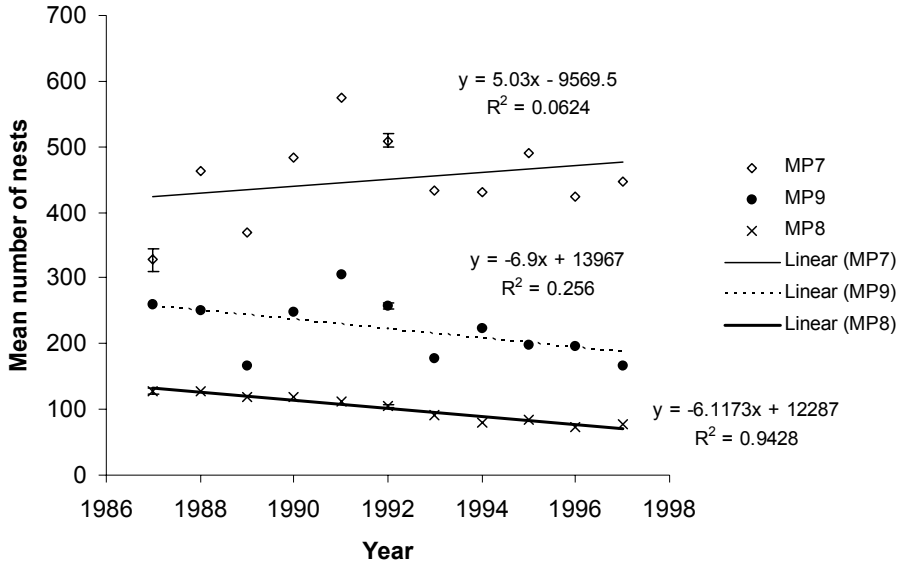


Figure 13. Trends in the number of nests at Hookers Peninsula (composed mainly of grey-headed mollymawks), counted from photographs taken from photopoints MP7, 8 and 9, 1987–97. All photographs were taken between late September and mid-November. Counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

Photopoint MP9

Central sub-colonies of eastern Hookers Peninsula also had a similar pattern of fluctuations, with a downward trend (of 2.5% p.a.; Table 4, Fig. 13).

3.2.7 Bull Rock North

Bull Rock North is a large colony near North Cape (Fig. 4), where 84% of nests were occupied by Campbell mollymawks during ground counts in 1995–97.

Photopoint MP11

MP11 is a relatively distant vantage point (c. 250 m from the colony) on a headland at the northern edge of Bull Rock South (Fig. 4) with an unobstructed view of most of the Bull Rock North colony. Six photographs were taken before 1986 and photographs were taken annually in 1986–97, creating the best photograph series for any colony on the island. Over the 55-year period 1942–97, there were large fluctuations in the number of nests (Fig. 14) and an

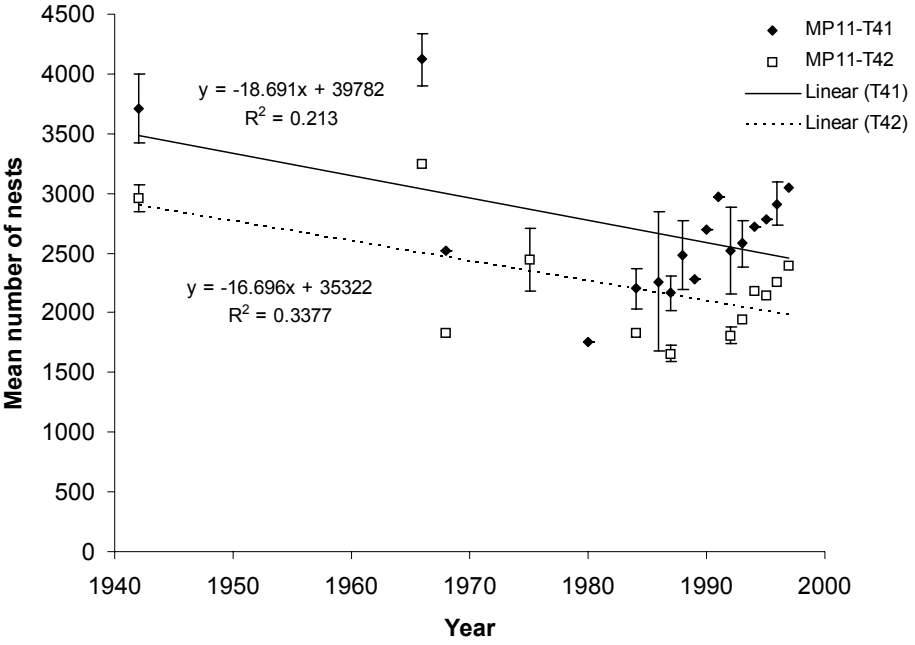


Figure 14. Trends in the number of nests at Bull Rock North (composed mainly of Campbell mollymawks), counted from photographs taken from photopoint MP11, 1942–97. Data for the whole view (count zone subtotal T41) and central view (T42) are plotted separately as the 1975 photograph encompassed the central view only. Most photographs were taken between late Sep and mid-Dec (exceptions were Jan 1969, Feb 1981, and Jan 1987). Counts of nests were converted to mid-Oct with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

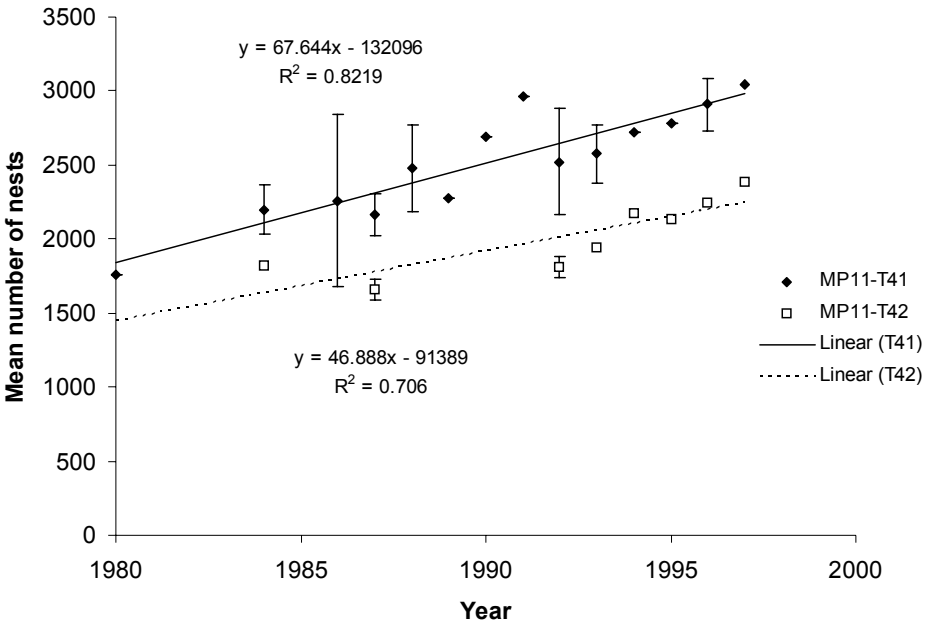


Figure 15. Trends in the number of nests at Bull Rock North (composed mainly of Campbell mollymawks), counted from photographs taken from photopoint MP11, 1980–97. Data for the whole view (count zone subtotal T41) and central view (T42) are plotted separately. Most photographs were taken between late Sep and mid-Dec (exceptions were Feb 1981 and Jan 1987). Counts of nests were converted to mid Oct. with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

overall decrease of 21.5% (Table 5, 0.5% p.a. Fig. 14). The numbers of nests increased between 1942 and 1966 by 11.1% (0.4% p.a.) to 4122 nests (a mean of three counts of an October photograph), and in addition, the colony area expanded slightly. The low estimate of 2517 nests for 1968 (a single count from a January 1969 photograph), may be an anomalous extrapolation to a mid-October figure, perhaps as a result of a poor breeding season, but is shown in Fig. 14 and included in the 1960s mean of Table 5. If the 1968 data is disregarded, there was a steady decline of 46.6% (a fall of 2.4% p.a.) in the number of nests from the higher mean of 4122 in 1966, through the 1970s, to the early 1980s. In contrast, there was an overall increase in the 1980s–90s of 32.3%, at a rate of 3.2% p.a. (Table 5; Fig. 15).

Photoviews BRN-1, BRN-2

Two photographs of uncertain date (possibly November, judging by other photographs in the negative strip) in 1950 were repeated in 1997. They were oblique views (Fig. 4) and poor quality enlargements of contact prints, resulting in approximate counts only. Counts of the larger view (BRN-1) suggested a small decrease in the number of nests between 1950 and 1997 (Table 5), with two ledges showing a reduction in nesting area; whereas a smaller oblique view (BRN-2) showed an increase (Table 5).

3.2.8 Bull Rock South

Bull Rock South is the largest accessible colony on Campbell Island and 95% of its nests were occupied by Campbell mollymawks during ground counts in 1995–97. Photographs were taken at two photopoints (MP10 and MP12, Fig. 4) during the 1980s–90s. Some earlier historical photographs tended to be oblique and limited in area coverage but were also compared with recent photographs taken from similar positions.

Photopoint MP10

Photographs of central and lower terraces (MP10a) and an upper terrace (MP10b) taken from the northern end of the colony during the 1980s–90s showed slightly increasing, although fluctuating, trends in the number of

nests (Table 5; MP10a: 0.6% p.a., MP10b: 0.9% p.a., Fig. 16); Other photograph montages of the north of the colony showed that the area occupied by nests decreased between 1966 and the 1990s.

Photopoint MP12

Photographs taken of central and lower ledges fluctuated widely between about 650–850 nests in the 1970s–80s (Fig. 16), but the 1990s data created an overall increasing trend (of 2.1% p.a., Table 5).

TABLE 5. ESTIMATED POPULATION CHANGE AT COLONIES DOMINATED BY CAMPBELL MOLLYMAWKS BY COMPARING MEAN NUMBER OF NESTS IN PHOTOGRAPH COUNTS FROM DIFFERENT PERIODS (1940S TO 1990–94) WITH 1995–97.

AREA	PHOTO-POINT OR PHOTO-VIEW	COUNT ZONE SUB-TOTAL†	MEAN NUMBER OF NESTS IN MID-OCTOBER AND THE PERCENTAGE CHANGE TO 1995–97*							
			1940s	1950s	1960s	1970s	1980–84	1985–89	1990–94	1995–97
Hookers	MP5	T25						668	630	583
Finger	MP5d	5d						88	67	59
Colonies 5, 6	MP6	T26						543	521	519
	MP5, 5d, 6	T25, T26, 5d						1299	1218	1161
	Change (%)							–10.6	– 4.7	
Bull	BRN-1			1431						1388
Rock	BRN-2			229						259
North	MP11	T42	2961		2538	2442	1824	1662	1936	2260
	MP11	T41– T42‡	748		1183		376	619	718	651
	MP11	T41	3709		3721		2200	2281	2654	2911
	Change (%)		–21.5		–21.8	–7.5	+32.3	+27.6	+9.7	
Bull	ST1	T71	112		150					194
Rock	ST2	T72			203					206
South	BBT	T69			696		552			
	SS1	T70			201		212			
	H1	T62			1837					1598
	MP10a	T33						651	624	656
	MP10b	T35						274	300	302
	MP12	T47				737	665	747	753	871
	MP10, MP12	T33, 35, 47						1672	1677	1829
	Change (%)							+9.4	+9.1	
Eastern colonies	E15	T76						1406		1315
	Change (%)							–6.5		
Courre-jolles	C1, C2, sea, air	T53/54			10 665	8397	8317	8278	8495	8102
	Change (%)				–24.0	–3.5	–2.6	–2.1	–4.6	
Peninsula	C1, C2, sea, air	T56				15 442	15 057	15 241	15 027	13 960
	Change (%)					–9.6	–7.3	–8.4	–7.1	

* Counts were converted to mid-October if necessary using the regression lines in Table A1.1 (Appendix 1), then averaged. Figures include means of multiple counts of individual photographs (e.g. most of the historical photographs 1940s–70s) and single or multiple counts of photographs in other years (e.g. 1980s–90s).

† Count zones of colonies were combined in a subtotal that was comparable in all years (Moore & Blezard 1999a, b).

‡ T41 minus T42 represents the periphery of the colony, since T41 is the full view and T42 the central view of the colony, which was the only part photographed in some years.

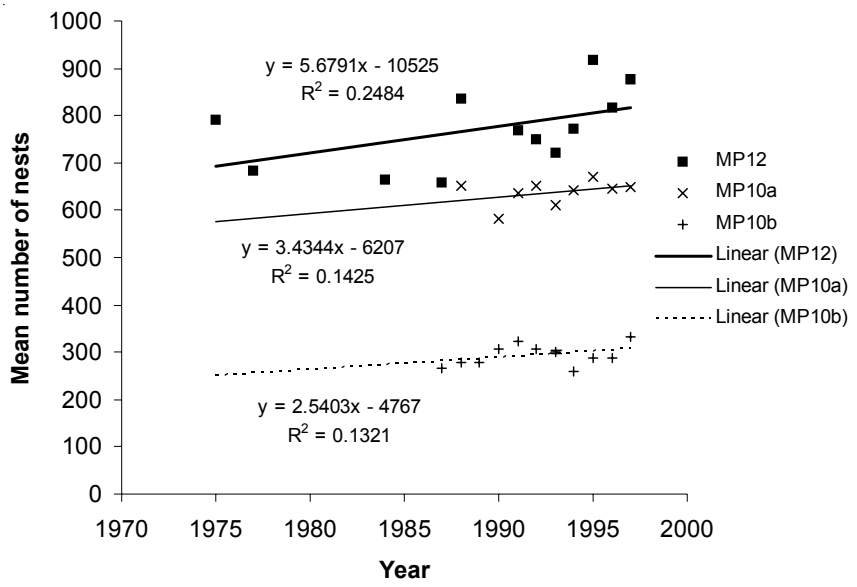


Figure 16. Trends in the number of nests at Bull Rock South (composed mainly of Campbell mollymawks), counted from photographs taken from photopoints MP10 (a and b) and MP12, 1975–97. All photographs were taken between late September and mid-December, except one taken in January 1978. Counts of nests were converted to mid-October with regression lines in Table A1.1. Points are means ± SD of multiple counts, or single counts.

The combined MP10a, MP10b and MP12 counts showed a 9% (1% p.a.) increase between the late 1980s and 1995–97 (Table 5).

Photoview H1

The numbers of nests in photographs at H1 showed a decrease of 13% between 1966 and 1997 (Table 5).

Photoview ST1/ ST2

At Sorensen Tarn, a small pond at the northern edge of the colony, nest numbers increased by 73.2% between 1942 and 1997 (Table 5: ST1), and a greater part of the pond was utilised for nests. A different view of the same pond yielded little difference between 1966 and 1997 (Table 5: ST2), although the equivalent count boundaries were difficult to judge.

Photoview BBT

A view of a large central terrace at the top of the colony showed that the numbers of nests decreased by 20.7% between 1966 and 1984 (Table 5). Peripheral areas of the terrace were occupied in 1966 but not in 1984 or the 1990s.

Photoview SS1

A small nesting area at the top ledge of the colony had similar numbers of nests and occupancy in 1966 and 1984 (Table 5).

3.2.9 Eastern Colonies

This covered an area of scattered colonies south of Bull Rock South (Fig. 4) where Campbell mollymawks occupied 82% of nests during ground counts in 1995–97.

Photoview E15

One view of the largest colonies on this section of coast showed a slight decrease (by 6.5%) in nest numbers between 1985 and 1997 (Table 5).

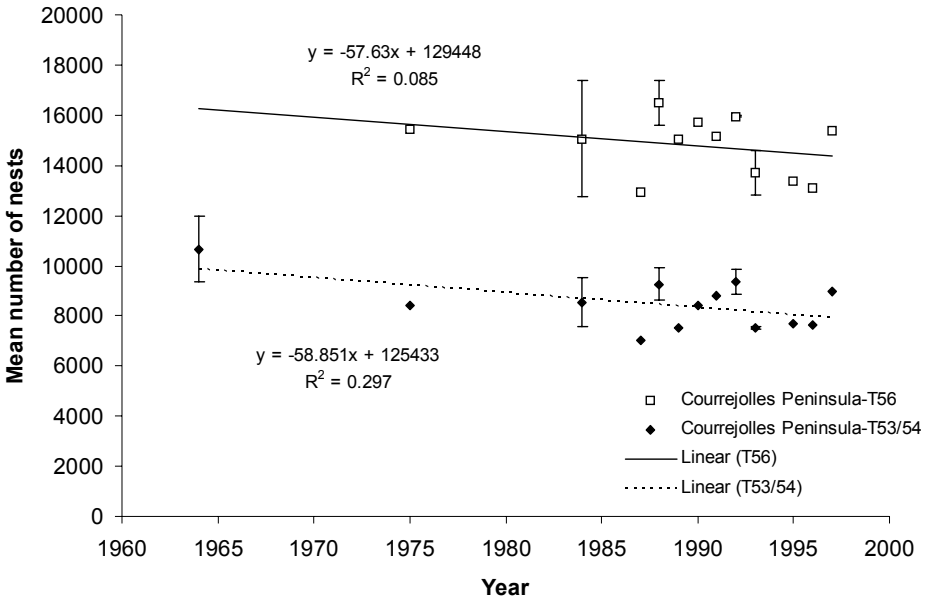


Figure 17. Trends in the number of nests at Courrejolles Peninsula (composed mainly of Campbell mollymawks), counted from photographs taken from land, sea and air, 1964–97. Data for the whole view (count zone subtotal T56) and central areas (T53/54) are plotted separately as the Jan 1965 photograph was an incomplete view. Most photographs were taken late Sep –early Dec (exceptions were Jan 1965 and Feb 1985). Counts of nests were converted to mid-Oct with the general Campbell mollymawk regression line (Table A1.1, Fig. A1.2). Points are means ± SD of multiple counts, or single counts.

3.2.10 Courrejolles Peninsula

Several large and inaccessible mollymawk colonies are found on the southern slopes of Courrejolles Peninsula (Fig. 2) and these were photographed from land, sea, and air in the 1960s–80s. These photographs were taken by different methods, but are considered equivalent for the purposes of this study, because the views were essentially at right-angles to the colonies and, therefore, relatively unobstructed. Most other photographs in the 1980s–90s were taken from the coast 2 km south of the peninsula. It was estimated that Campbell mollymawks occupied c. 67% of nests in 1995–97, using a combination of photograph counts of all nests and telescope counts of nests occupied by grey-headed mollymawks.

Photoviews from land (C1, C2), sea, and air

A telephoto photograph of the central colonies in January 1965 (count zone subtotals T53 and T54) was of lower quality and magnification than recent photographs, and counters used a slide projection or different-sized prints, resulting in variable estimates of the numbers of nests by the three counters. Nevertheless, combined with counts of photographs taken through the 1970s–90s, it suggested that there was a 24% decrease in the number of nests in the central part of the colony between 1964 and 1995–97 (Table 5) at a rate of 0.6% p.a. (Fig. 17), in addition to a decrease in the area used by nesting birds. Counts of nests on the whole peninsula (T56) during the 1970s–90s showed a similar overall decreasing trend (of 0.4% p.a., Fig. 17; Table 5).

3.3 PRECISION AND ACCURACY OF GROUND COUNTS

Some sectors of colonies were counted more than once to test the precision of different ground count methods (Table 6). Binocular views across to Bull Rock North were easiest to conduct as they were not time-consuming and did not disturb the colony, hence this category had the largest sample size (Table 6).

TABLE 6. PRECISION OF GROUND COUNT METHODS USED FOR PHOTOGRAPH COUNTS OF MOLLYMAWK NESTS ON CAMPBELL ISLAND IN 1995–97, EXPRESSED AS THE MEAN CV AND ITS STANDARD DEVIATION (SD).

	MEAN CV OF REPLICATED COUNTS (%)	SD OF CV	N	DETAILS OF REPLICATIONS*
Binocular view across	3.4	2.5	40	1–3 counters × 1–4 counts each
Nest visit	4.6	2.7	11	3 counters × 1 count each
Binocular view down	4.9	3.5	12	1–3 counters × 1–3 counts each
Ledge	5.2	0.5	4	3 counters × 2–5 counts each
View down	11.0	8.0	2	2 counters × 2–3 counts each
Telescope	22.6	16.7	10	2 counters × 1–2 counts each

* Each set of counts at a colony sector on the same day made by 1–3 counters using the same method was considered one replication.

This was the most precise count method, having a 3.4% mean CV in replicated counts, followed by nest visits, binocular views down, and ledge counts, which all had similar precision with CVs of around 5% (Table 6). Views down and telescope counts were the least precise methods (Table 6).

In comparison with nest visit counts, other count methods tended to give lower estimates of the number of nests (Table 7). Ledge counts and binocular views across had similar means (< 2% fewer nests) to nest visit counts, although the binocular views were more variable than ledge counts. Views down and binocular views down had the greatest discrepancy in the number of nests compared with nest visits (Table 7).

There was no significant observer bias for most methods, except for the most distant viewing methods (binocular across and telescope; Table 8).

Three of the most reliable methods (nest visit, ledge, and binocular view across) were used to count c. 87% of grey-headed mollymawk nests and c. 93% of Campbell mollymawk nests during ground counts at accessible colonies in 1995–97 (Tables 1, 9, and 10). A small number of counts were timed. Nest visits took the longest time to carry out (6.7 ± 1.6 nests/min., N = 20). Because birds were marked on the chest as the counter proceeded, the process was relatively straightforward. Ledge counts took less time (13.8 ± 6.2 nests/min., N = 8), but were more difficult for the counter, who relied on landmarks to keep track of which birds had been counted. Binocular view across counts took the least time (18.3 ± 6.1 nests/min., N = 3).

TABLE 7. BIAS OF GROUND COUNT METHODS USED TO COUNT MOLLYMAWK NESTS ON CAMPBELL ISLAND IN 1995–97, EXPRESSED AS THE DEVIATION (%) FROM THE 'NEST VISIT' COUNT FOR THE SAME AREA AND ITS SD.

GROUND COUNT METHOD	MEAN DEVIATION (%) FROM NEST VISIT COUNT	SD	N
Ledge	–1.6	5.1	12
Binocular view across	–2.0	10.1	16
View down	–8.8	9.4	13
Binocular view down	–18.5	12.3	11

TABLE 8. COUNTER BIAS DURING COUNTS OF MOLLYMAWK NESTS ON CAMPBELL ISLAND IN 1996 (counters: P.M., A.W., and M.C.) AND 1997 (counters: A.W., S.H., and B.E.), EXPRESSED AS THE MEAN PERCENTAGE DEVIATION IN THE NUMBER OF NESTS FROM THE MEAN COUNT PLUS STANDARD DEVIATION (SD).

	COUNTER BIAS*											
COUNTER (initials)	P.M.		A.W.		M.C.		S.H.		B.E.		N	ANOVA
Ground count method	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD		
Nest visit			0.6	3.6			1.8	3.5	-2.3	5.1	11	$F_{2, 30} = 2.9, P = 0.07$
Ledge	2.1	3.3	1.1	4.9	-3.2	2.3					4	$F_{2, 9} = 2.4, P = 0.15$
View down			12.7				3.2		8.0	6.7	2	$F_{2, 1} = 3.3, P = 0.36$
Binocular view down	1.9	5.9	-0.7	5.3	-3.7	5.5	6.4	4.3	-3.8		8	$F_{4, 16} = 1.5, P = 0.26$
Binocular view across	-1.1	5.5	-3.4	3.0	4.9	5.5	2.3	3.6			13	$F_{3, 31} = 6.8, P < 0.01$
Telescope view			10.7	19.5			-10.7	19.5			10	$F_{1, 18} = 6.0, P < 0.05$

* Percentage deviation from mean number of nests.

TABLE 9. GROUND COUNTS OF GREY-HEADED MOLLYMAWK NESTS AT ACCESSIBLE COLONIES ON CAMPBELL ISLAND, 1992–97, WITH ADJUSTMENTS TO ACCOUNT FOR DIFFERENT COUNT METHODS AND SURVEY TIMING. ALSO INCLUDED ARE ESTIMATES OF THE NUMBER OF NESTS AT INACCESSIBLE COLONIES (COURREJOLLES PENINSULA) FROM PHOTOGRAPH COUNTS AND TELESCOPE COUNTS.

	NUMBER OF NESTS						
YEAR	1992	1993	1994	1995	1996	1997	1995–97 MEAN
MONTH	Late Sep	Late Oct	Sep/Oct	Mid Oct	Mid Oct	Mid Oct	Mid Oct
Courrejolles Isthmus	430	294	377	299	350	319	
Hookers Finger	1233	737	1099	913	955	832	
Hookers Peninsula	718		642	532	606	511	
Bull Rock North	653		606	459	530	545	
Bull Rock South	642		550	469	485	400	
Eastern Colonies	676		428	471	541	490	
Total at accessible colonies	4352		3702	3143	3467	3097	3236
Nest visit estimate*	4577		3900	3254	3499	3130	3295
Mid October estimate†	4178		3560				
Percentage of nests with eggs (from nest visits)				76.3%	81.9%	80.3%	79.5%
Month for Courrejolles Pen. photograph or count	Oct	Late Oct		Late Oct	Late Oct	Mid Oct	
Courrejolles Pen. photo (1992–95) or telescope count (1996–97)‡	5477	3372			4685	4217	4451
Courrejolles Pen. mid-October estimate†	5477	3529		4589	4774	4217	4527
Total grey-headed mollymawk nests (rounded to nearest 100)	9700		7100	7800	8300	7300	7800

* Correction for the proportion of nests counted by various methods (Table 1) and the relative under-estimate compared with the more intensive 'nest visit' count method (see Table 7).

† Adjustments to mid-October using ground count regression line (Fig. A1.3), or the photo count regression line (Fig. A1.1) for Courrejolles Peninsula in 1993. The mean Courrejolles Peninsula count of 1996 and 1997 (1996–97) is used for 1995.

‡ Estimate of number of grey-headed mollymawk nests on Courrejolles Peninsula, based on 'photograph counts' of nests in predominantly grey-headed mollymawk areas (identified by telescope in 1992) in photographs (1992, 1993); or 'telescope counts' of grey-headed mollymawk nests (1996–97).

TABLE 10. GROUND COUNTS OF CAMPBELL MOLLYMAWKS ON CAMPBELL ISLAND, 1992–97, WITH ADJUSTMENTS TO ACCOUNT FOR DIFFERENT COUNT METHODS AND SURVEY TIMING. ALSO INCLUDED ARE ESTIMATES OF THE NUMBER OF NESTS AT INACCESSIBLE COLONIES (COURREJOLLES PENINSULA) FROM PHOTOGRAPH COUNTS AND TELESCOPE COUNTS.

	COUNT OF CAMPBELL MOLLYMAWK NESTS						
YEAR	1992	1993	1994	1995	1996	1997	1995–97 MEAN
MONTH	Late Sep	Late Oct	Sep/Oct	Mid Oct	Mid Oct	Mid Oct	Mid Oct
Courrejolles Isthmus	79	72	80	83	82	89	
Hookers Finger (Colonies 2, 3, 5, 6)	1357	1166	1286	1309	1233	1205	
Hookers Peninsula	391		403	375	402	406	
Bull Rock North	2633		2524	2753	2846	2701	
Bull Rock South	7958		7626	7952	8375	8023	
Eastern Colonies	2413		2019	2116	2411	2245	
Total at accessible colonies	14 831		13 938	14 588	15 349	14 669	14 869
Nest visit estimate*	15 170		14 260	15 100	15 620	14 940	15 220
Mid-October estimate†	14 953		14 061				
Percentage of nests with eggs (from nest visits)				85.8%	84.5%	85.3%	85.2%
Month for Courrejolles Pen. photograph or count	Oct	Late Oct		Late Oct	Late Oct	Mid Oct	
Courrejolles Pen. photo (1992–95) or telescope count (1996–97)‡	10 518	10 001		8576	8065	10 996	9452
Adjusted Courrejolles mid-October estimate†	10 518	10 258		8849	8285	10 996	9377
Total Campbell mollymawk nests (rounded to nearest 100)	25 500		24 300	23 900	23 900	25 900	24 600

* Correction for the proportion of nests counted by various methods (Table 1) and the relative under-estimate compared with the more intensive 'nest visit' count method (see Table 7).

† Adjustments to mid October using ground count regression line (Fig. A1.4) for accessible colonies and photo count regression lines (Fig. A1.2) for Courrejolles Peninsula.

‡ Estimate of the number of Campbell mollymawk nests by subtracting grey-headed mollymawk estimate (Table 9) from total 'photograph count' of Courrejolles Peninsula for all years.

A test of the amount of variation in the number of nests recorded between days and within the same day was measured for nest visit counts by one observer at Bull Rock South (Fig. 18). The CV of nests (with and without eggs) was 1.5% between days and 0.9% within the same day because of relatively small changes in the number of birds sitting on empty nests. A greater difference in 'extras' occurred with 45 counted on the first day and 75–100 on the second day, accounting for 15.6%–25.3% of the total number of birds present. There was a decrease in the number of extras during the day. Other indications of variation during the day were replicate ledge counts conducted by three observers over the course of 4–5 hours on 8 October 1996. These had a mean CV of 4.3% ± 1.6% in the number of nests (N = 3 areas of Bull Rock South), however, this partially reflects observer bias.

Results of ground counts in 1992–97 are provided in Tables 9 and 10. To adjust for under-counting when using methods other than 'nest visits', numbers of nests were adjusted using the mean percentage differences in Table 7. Data from ground counts in 1992 and 1994 were adjusted to mid-October values, based on the regression lines in Figs A1.3 and A1.4 (Appendix 1), to be comparable with the timing of counts in 1995–97. Photocounts and 'telescope

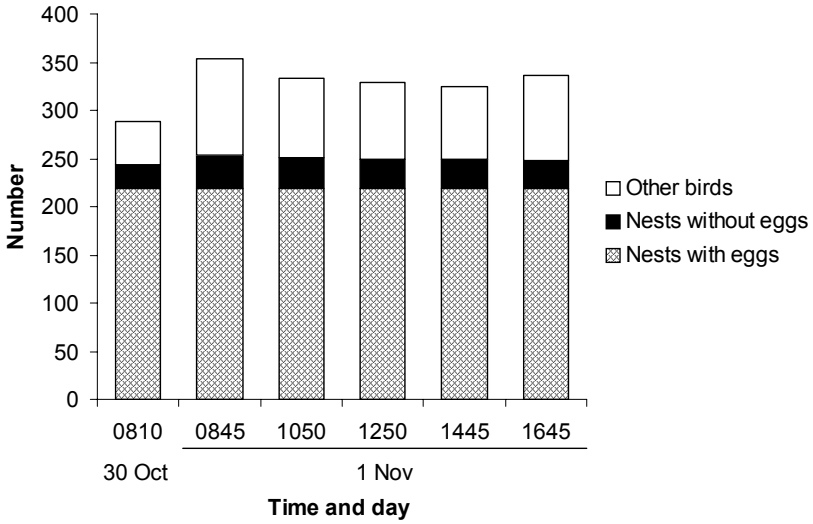


Figure 18. Comparison of nest visit ground counts at Bull Rock South between days (30 October and 1 November 1996) and at different times of the same day (NZST). Nests with eggs were counted once only, but nests without eggs and other birds (extras) were counted at other times.

views' of Courrejolles Peninsula were adjusted to mid-October values, based on the regression lines in Figs A1.1 and A1.2 (Appendix 1), to provide estimates of the total number of mollymawks on Campbell Island.

The total number of birds (on nests and 'extras') was counted during all ground counts of accessible colonies in mid-October 1995–97, and the percentage of grey-headed mollymawks on nests (88.7% ± 1.25%, N = 3 years) was similar to Campbell mollymawks (87.7% ± 0.66%). Counts from distant vantage points (e.g. telephoto photographs or telescope views) of the inaccessible colonies of the Courrejolles Peninsula might overestimate (by up to 12%) the number of nests, since non-nesting birds could be counted as nesting birds. However, this was offset to an unknown degree by non-breeders being hidden behind nesting birds and their nest pillars, and by counters using cues, such as the regular spacing of birds, to distinguish the nests.

3.4 GROUND COUNTS

3.4.1 Grey-headed mollymawks

Of the total number of grey-headed mollymawk nests counted at accessible colonies in 1995–97, 47% were in four colonies where the species predominated and the remaining 53% were in five colonies dominated by Campbell mollymawks (Tables 9 and 10, Fig. 19).

The number of grey-headed mollymawk nests decreased at all accessible colonies, regardless of which species predominated (Tables 9 and 10, Fig. 19). There was a decrease of 883 nests (21%) between 1992 and 1995–97 (Table 9, Fig. 19) and a mean of 3672 ± 585 nests for all years in the 1990s (N = 5).

At the inaccessible colonies of Courrejolles Peninsula, the status of grey-headed mollymawks was estimated from photograph counts of nests in areas of the peninsula that were dominated by grey-headed mollymawks (1992, 1993) and telescope counts of all grey-headed mollymawk nests on the peninsula in 1996 and 1997. Overall, there was a decrease of 950 nests (17%) between 1992 and 1995–97 (Table 9, Fig. 19), although the low estimate in 1993 suggested a much larger fluctuation in numbers. The 1993 figure may be an underestimate,

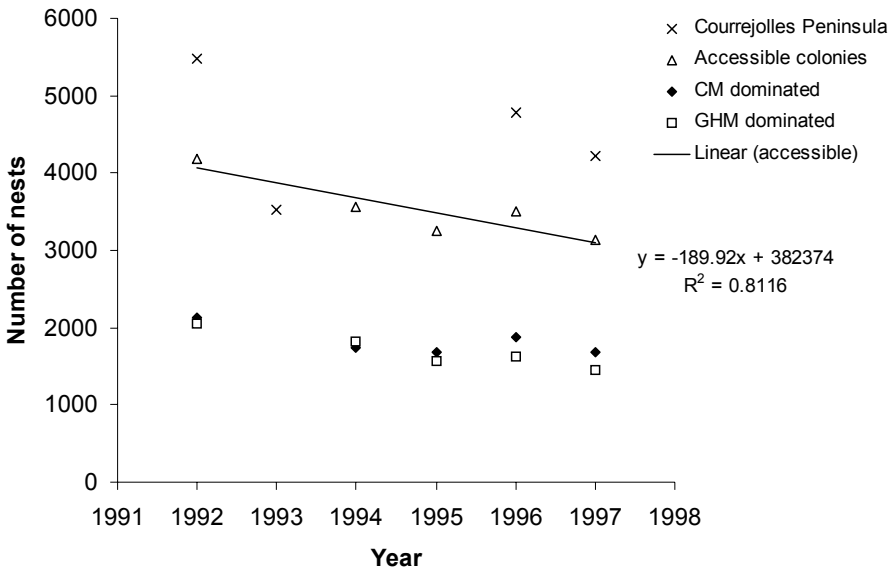


Figure 19. Trends in the number of grey-headed mollymawk nests on Campbell Island, 1992–97. Numbers of nests at accessible colonies are shown as total ground counts (adjusted for method and timing; a straight line regression is fitted), and separately for colonies dominated by grey-headed mollymawks (GHM) or those dominated by Campbell mollymawks (CM). The plot of the number of GHM nests at the inaccessible colonies of Courrejolles Peninsula is a combination of 'photograph counts' (1992–93) and 'telescope counts' (1995–97) (Table 9).

perhaps because of photograph quality, counter variation, or early breeding losses, however, the ground counts of Courrejolles Isthmus and Hookers Finger in 1993 were also below average (Table 9). The mean estimate for all years in the 1990s was 4517 ± 717 nests.

The total estimate of grey-headed mollymawk nests in 1995–97, including both accessible and inaccessible colonies, was 7800 nests (Table 9). The proportion of nests with eggs was 79.5% (Table 9), hence approximately 6200 nests had eggs, up to 400 were yet to lay (c. 6% of birds laid during the counting period) and 1200 nests were occupied by other birds (failed breeders and non-breeders).

3.4.2 Campbell mollymawks

Ground counts at accessible colonies in 1992–97 showed that Campbell mollymawks were concentrated in distribution, with 88% of nests being at three neighbouring areas (Bull Rock North, Bull Rock South, and Eastern Colonies) and 95% of nests were in colonies that they dominated (Tables 9–10, Fig. 20).

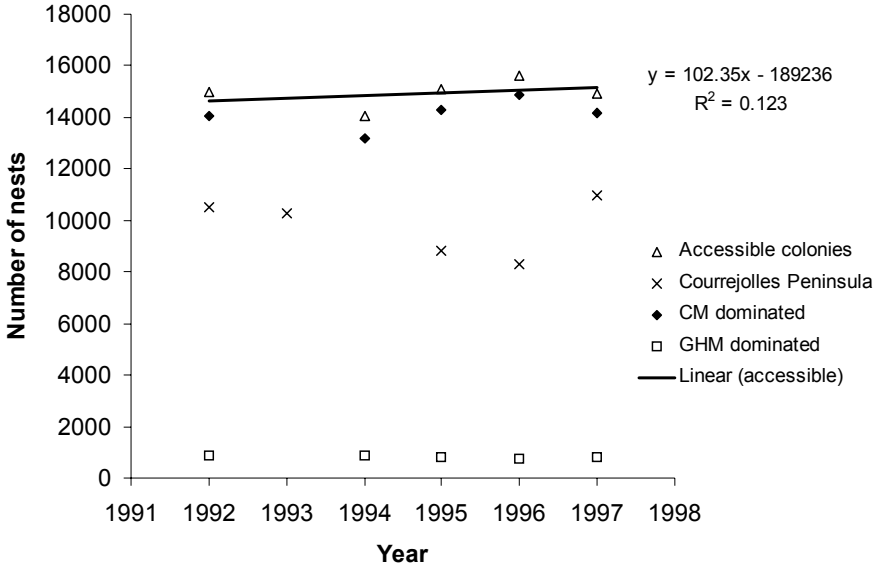


Figure 20. Trends in the number of Campbell mollymawk nests on Campbell Island, 1992–97. Numbers of nests at accessible colonies are shown as total ground counts (adjusted for method and timing; a straight line regression is fitted), and separately for colonies dominated by grey-headed mollymawks (GHM) or those dominated by Campbell mollymawks (CM). The plot of the number of CM nests at the inaccessible colonies of Courrejolles (Table 10) was calculated from photograph counts of all nests minus the GHM estimate.

The number of Campbell mollymawk nests increased at six of the accessible colonies (Courrejolles Isthmus, Hookers Finger 3 and 6, Hookers Peninsula, Bull Rock North and South) and decreased at three others (Hookers Finger 2 and 5, and Eastern Colonies). The total number of nests at accessible colonies was similar in 1992 and 1995–97 (adjusted figures increased slightly by 267 nests; up 1.8%, Table 10), although there were fluctuations from 14 000 to 15 600 nests between years (Fig. 20). The overall mean was 14 934 ± 562 nests during the 1990s.

At the inaccessible colonies of Courrejolles Peninsula, the number of Campbell mollymawk nests was calculated by subtracting the estimate of grey-headed mollymawk nests from the total photograph counts of all nests, and adjusting for the time of the season that photographs were taken (Table 10). Adjusted estimates fluctuated between a low of 8300 nests in 1996 and a high of 11 000 the next year, with an overall mean of 9781 ± 1157 nests during the 1990s (Table 10).

The total estimate of Campbell mollymawk nests in 1995–97, including both accessible and inaccessible colonies, was 24 600 nests (Table 10). The proportion of nests with eggs was 85.2% (Table 10), hence approximately 21 000 nests had eggs and 3600 nests were occupied by other birds (failed breeders and non-breeders).

3.5 COMPARISON BETWEEN PHOTOGRAPH AND GROUND COUNTS

The number of mollymawk nests found in ground counts (combined species totals) and photograph counts were plotted in Figs 21–22 to compare trends found with the different methods. Counts of nests in aerial photographs (1984, 1989 and 1990) were also plotted for comparison since, as they had unrestricted views of whole colonies, they might be the closest equivalent to the ground counts conducted during the 1990s. As previously, data were adjusted (aerial photos were taken in November–February) to an estimated mid-October figure using the appropriate regression lines (Figs A1.1–A1.4,

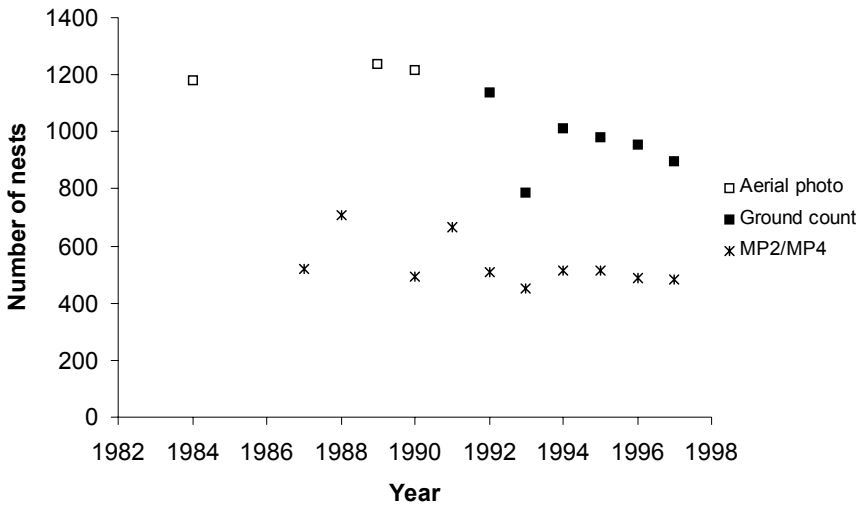


Figure 21. Comparison between ground counts of mollymawk nests at Hookers Finger Colonies 2–3 (neighbouring grey-headed mollymawk-dominated colonies) and photograph counts of aerial photographs and photographs taken from photopoints MP2 and MP4 in the 1980s–90s. Counts are combined totals of Campbell and grey-headed mollymawk nests at both colonies.

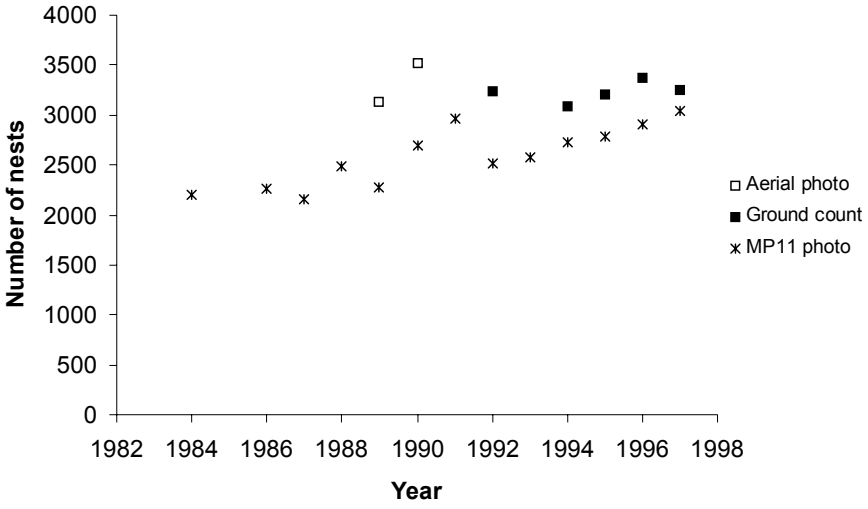


Figure 22. Comparison between ground counts of mollymawk nests at Bull Rock North (a Campbell mollymawk-dominated colony) and photograph counts of aerial photographs and photographs taken from photopoint MP11 in the 1980s–90s. Counts are combined totals of Campbell and grey-headed mollymawk nests.

Appendix 1). It was expected that counts from aerial photographs would be less precise than ground counts, as non-nesting birds may be confused with nesting birds and the 1984 photographs were taken late in the breeding season (in February 1985).

Most colonies showed similar trends and patterns of fluctuations in numbers of nests between ground counts (and aerial photograph counts) of the whole colony and photograph counts at the same colony (P.J.M., unpubl. data). Two examples are shown. At Hookers Finger Colonies 2 and 3 there was a more steady decrease in total nest numbers shown by the aerial photograph and ground counts than by the smaller area covered by the photograph counts (Fig. 21). The relatively low ground count in 1993 suggests a counting error occurred that year (Fig. 21). At Bull Rock North the pattern of fluctuations was similar between counting methods (Fig. 22), as was the magnitude of counts, as most of the nesting area was visible from the photopoint.

3.6 POPULATION ESTIMATES

Table 11 combines the information from ground counts in 1995–97 (Tables 9–10) and the changes shown from comparisons between historical and modern-day photographs (Tables 4–5) to produce estimates of total populations of grey-headed mollymawks and Campbell mollymawks in previous decades.

The estimate of 43 000 grey-headed mollymawk nests in the 1940s (Table 11) used the overall rates of changes at colonies that were dominated by grey-headed mollymawks, and had photographs taken in the 1940s (Courrejolles Isthmus and Hookers Finger Colonies 2 and 3), and extrapolated back from the total estimate of 7800 grey-headed mollymawk nests in 1995–97 (Table 9).

Similarly, the estimate of 31 300 Campbell mollymawk nests in the 1940s (Table 11) used the changes observed from photopoint MP11 at Bull Rock North (the colony with the most complete photographic record and which is dominated by Campbell mollymawks). These changes were extrapolated back from the estimate of 24 600 Campbell mollymawk nests in the 1995–97 (Table 10).

TABLE 11. ESTIMATED ANNUAL NUMBER OF NESTS OF CAMPBELL MOLLYMAWKS AND GREY-HEADED MOLLYMAWKS ON CAMPBELL ISLAND 1940s–90s; AND ESTIMATED* NUMBERS OF NESTS IN COLONIES DOMINATED BY EITHER SPECIES.

	ESTIMATED ANNUAL NUMBER OF NESTS				
	1940s	1960s	1970s	1980s	1990s
SPECIES ESTIMATE					
Grey-headed mollymawk†	43 000	35 000	22 200	9400	7800
Campbell mollymawks‡	31 300	34 800	26 600	19 300	24 600
COLONY ESTIMATE					
Grey-headed mollymawk- dominated colony§	14 200	8900	5600	2600	2300
Campbell mollymawk- dominated colony§	38 600	38 800	30 700	30 200	30 100

* Estimates are based on rates of change in colonies that have photographs from all time periods and ground counts from 1995–97.

† Estimated from mean proportional change of nest numbers from photopoints at colonies dominated by grey-headed mollymawks and extrapolated from mean total estimate of grey-headed mollymawk nests in 1995–97.

‡ Estimated from proportional change of nest numbers at Bull Rock North (MP11) and extrapolated from mean total count of Campbell mollymawk nests in 1995–97.

§ Estimate of total number of mollymawk nests based on proportional change of nest numbers at colonies dominated by grey-headed or Campbell mollymawks; colonies without a complete photograph series were assumed to have changed in the decades before the first photograph at the same average rate as other grey-headed-dominated colonies, or as Bull Rock North for Campbell-dominated colonies.

An alternative approach was to estimate the total population size of individual colonies using only the available photographic evidence. This suggests there may have been a decrease from 38 600 to 30 100 nests between the 1940s and the 1990s at colonies now dominated by Campbell mollymawks; and a decline from 14 200 to 2300 nests at colonies dominated by grey-headed mollymawks (Table 11).

4. Discussion

The purpose of the study was to establish historical population trends for mollymawk species on Campbell Island over an approximately 55-year period; current population baselines; and methods for future monitoring. The main findings are listed below.

- Between the 1940s and 1990s grey-headed mollymawk colonies showed a long-term and apparently continuous decline in nest numbers; approximately 6600 grey-headed mollymawk pairs bred annually in 1995–97, and if at least 44% of birds deferred breeding for more than one year (calculated from table 3 in Waugh, Weimerskirch, Moore & Sagar 1999), then more than 11 800 pairs existed at that time.
- Campbell mollymawk numbers fluctuated over the same 55-year period. The main period of decrease was during the 1970s–80s, after which numbers began to recover. Approximately 21 000 pairs bred annually in 1995–97. Assuming at least 10% of birds defer breeding (calculated from table 3 in Waugh, Weimerskirch, Moore & Sagar 1999), this may represent a breeding population of 23 300 pairs.

4.1 ERRORS AND ASSUMPTIONS

Repeat counts of photographs had coefficients of variation (CVs) of 6.6% and the main ground count methods had CVs of between 3% and 5%. Most ground count methods underestimated numbers when compared with nest visit counts (physically marking birds), but numbers from ledge counts and binocular views across were, on average, within 2% of the nest visit count. Nest visit counts were expected to be more precise than any other technique, as they required less concentration by counters, however their mean CV of 4.6% was similar to 'ledge' counts and 'binocular views across'. Further comparisons of count methods would clarify if this is true in all years.

The combined use of counts of nests in photographs (photograph counts) and in the colonies themselves (ground counts) was useful for monitoring mollymawk populations on Campbell Island as it dove-tailed the historical period (photographs only) with the modern period (photographs and ground counts). Photograph counts allowed long-term population trends of colonies to be followed and assessment of inaccessible colonies; while ground counts enabled the species composition to be established and whole colonies to be surveyed. In the 1980s–90s, overall trends in the numbers of nests at colonies were similar for both techniques, giving credence to the estimated trends for the historical photograph period.

The assumption that the number of nests counted in mid-October in a particular year was an index for the number of breeding pairs present was reasonable, since a high proportion of nests were occupied by birds with eggs (80–85% for both species) and egg-laying was almost complete by the second week in October. However, fluctuations or trends in nest numbers between years were likely to be due to a combination of the total number of breeding pairs alive and changes in their breeding frequency. Large-scale and long-term changes will largely reflect the former, and short-term fluctuations the latter (Prince 1985). Whether birds breed is influenced by their body condition, survival of their partners and, particularly for biennial breeders, breeding success the previous season.

Breeding success of the Campbell mollymawk, an annually breeding species, was consistently high in the 1980s–90s (Fig. 23), with 65.5% ± 11.6% of eggs producing chicks close to fledging in March–April (N = 6 years). Similar proportions of successful (83%) and failed (74%) breeders returned to breed in the year following a breeding attempt, or an average of 81% (69%–90%) breeders (1991–94, calculated from table 3 in Waugh, Weimerskirch, Moore & Sagar 1999). This suggests that numbers of nests could vary by 10%–31% as a result of changes in breeding frequency, however, these figures may have been influenced by inconsistent band recovery between years.

Breeding success of the grey-headed mollymawk, a biennially breeding species, was lower and much more variable in the 1980s–90s than that shown by the Campbell mollymawks (Fig. 23), since only 36.4% ± 17.3% of eggs produced chicks close to fledging in April–May (N = 6 years). Most (72%) failed breeders returned in the year following a breeding attempt, and 62% of successful breeders returned 2 years later (Waugh, Weimerskirch, Moore & Sagar 1999), as expected for a biennially breeding species (Prince 1985). Overall this resulted in an average of 42% (29%–54%) of birds that bred in successive years and at

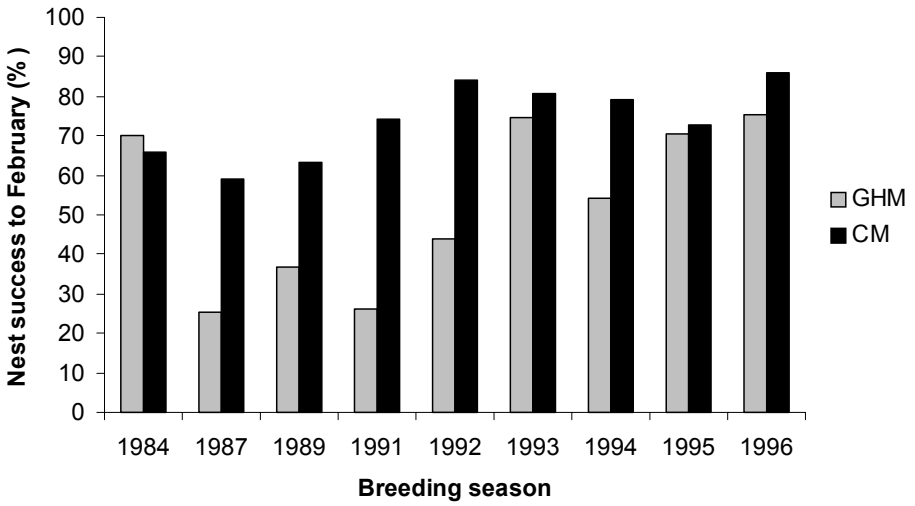


Figure 23. Breeding success to February of grey-headed mollymawks (GHM) and Campbell mollymawks (CM) at Bull Rock South on Campbell Island in the 1980s–90s (40–324 eggs per year, per species; Taylor 1986; Moore & Moffat 1990a; Waugh, Weimerskirch, Moore & Sagar 1999; Moore unpubl.; Waugh unpubl.).

least 44% that deferred breeding (for 1991–94, calculated from table 3 in Waugh, Weimerskirch, Moore, & Sagar 1999). Very low levels of breeding success normally cause high colony attendances the following year if food shortages do not prevent the birds getting into breeding condition (Prince 1985; Prince et al. 1994). For example, breeding success of grey-headed mollymawks on Campbell Island was low in 1991 (Fig. 23), and could explain why ground counts found higher numbers of nests in 1992 than in following years. However, only 65% of failed breeders from 1991 bred the following year, compared with over 80% in some years (Waugh, Weimerskirch, Moore, & Sagar 1999), hence a relatively high level of deferred breeding would offset the expected increase in colony attendance. These data illustrate the complexity of the biennial breeding pattern and the need to monitor colony size over a long period, preferably in combination with banding and breeding studies.

Another assumption was that the number of nests decreased during the breeding season at a similar rate to the breeding success, and that this rate could be used to convert photograph counts of nests to mid-October values. There was good evidence for this for most years, however, in some counts of nests in December (hatching stage) or January (early chick rearing), nest numbers were overestimated, possibly because large numbers of breeding partners and non-breeders were present in the colonies and these were counted as nesting birds. Similarly, the conversion of some counts of nests in historical photographs taken later in the season (January–February) resulted in apparently anomalous mid-October figures. This is presumably because the breeding success that year, or at that colony, was unusually low.

4.2 PREVIOUS OBSERVATIONS

Prior to the 1940s there were few historical accounts which indicated the former size or distribution of the mollymawk population on Campbell Island. In 1874 Campbell mollymawks were very abundant around the island and nested on the southern cliffs between Southeast Harbour and Perseverance Harbour (Filhol 1885). Westerskov (1960) cast doubt on this, suggesting that as current nesting areas were on the north coast and Filhol gave no detailed observations, he was probably using unreliable second-hand information. Filhol (1885) also noted that

the yellow-nosed mollymawk (*Thalassarche chlororhynchos*) nested in much smaller numbers than Campbell mollymawks, but was probably referring to the similar-looking grey-headed mollymawk (Westerskov 1960). A photograph of Bull Rock South in February 1895, although too blurred to count the birds effectively, showed that the occupancy on the central ledges of the colony was roughly similar to that seen in the 1990s. Interestingly, no grey-headed mollymawks were visible in 1895 in an area where approximately 40 pairs nested in the 1980s–1990s. In about 1927 Oliver (1930) noted an 'immense' colony of Campbell mollymawks on the north-east coast of Campbell Island.

During the 1940s, J. Sorensen, a naturalist with the Cape Expedition coast watching party, noted there were 'tens of thousands' or 'hundreds of thousands' of mollymawks nesting on Campbell Island (Sorensen 1951), although no attempt to estimate numbers was made (Bailey & Sorensen 1962). Colonies at the Courrejolles Peninsula and the North Cape (Bull Rock) were described as 'very large' (Bailey & Sorensen 1962), 'immense' (Sorensen 1951) or as containing 'tens of thousand' of birds (Sorensen 1943). Campbell mollymawks and grey-headed mollymawks shared the same colonies, but each species dominated at different colonies. It was not known which species was more numerous because the Courrejolles Peninsula colonies, which were the largest on the island with 'thousands and thousands of sitting birds' (Sorensen 1943, 1947), were inaccessible. In that area, nests covered the slopes to low elevation, including ledges that were not greatly above sea level (Sorensen 1944).

At the Courrejolles Isthmus, grey-headed mollymawks were in the majority, with only small patches of up to 12 Campbell mollymawks amongst hundreds of grey-headed mollymawks (Sorensen 1943; Bailey & Sorensen 1962). Further east (probably at Hookers Finger), two out of three colonies (probably Colonies 2 and 3) were dominated by grey-headed mollymawks (Sorensen 1943), but with a larger component of Campbell mollymawks than at Courrejolles Isthmus (Sorensen 1944). At the lower of the two colonies (Hookers Finger Colony 3), situated on a point, there did not appear to be any Campbell mollymawks (Sorensen 1943). At the third colony in the area (probably Hookers Finger Colony 5), Campbell mollymawks were numerically greater, with fewer grey-headed mollymawks situated above and below (Sorensen 1943). No mention was made of a fourth colony (Colony 6), although this could have been overlooked by Sorensen if he did not travel beyond Colony 5. A colony to the east of Hookers Finger (probably Hookers Peninsula) was seen from the sea but not visited (Sorensen 1947). The North Cape (Bull Rock) colonies were the second largest aggregation of mollymawks on the island. They were predominantly composed of Campbell mollymawks, with only a few grey-headed mollymawks on the outskirts (Bailey & Sorensen 1962) or dotted among them (Sorensen 1943). Several small colonies (the Eastern colonies) were noted among the scrub further south from Bull Rock (Sorensen 1943).

The 1940s distribution of colonies and species dominance appears to be similar to that observed in the 1990s. Observations in 1958 supported or repeated Sorensen's anecdotal accounts, although the Courrejolles Isthmus colony was the only area visited (Westerskov 1960; Bailey & Sorensen 1962).

Robertson (1980) estimated that there were 74 800 Campbell and 11 500 grey-headed mollymawk pairs breeding on Campbell Island in 1975 from brief visual

impressions of the colonies (C.J.R. Robertson, pers. comm.). However, counts of Robertson's photographs at Courrejolles Peninsula, Bull Rock North and Hookers Peninsula colonies suggested that he over-estimated colony size by a factor of at least 2.5 (Moore & Moffat 1990a).

In the 1980s it was clear from comparison of photographs that some colonies had declined, both in numbers of birds and nesting area, since the 1940s and 1990s (D. Cunningham pers. comm.; G. Taylor pers. comm.). Many nesting areas had been abandoned and old nest sites were overgrown with vegetation, including large tussocks which would have taken many years to grow. In 1988 it was estimated that there were 19 000–26 000 breeding pairs of Campbell mollymawks and 3000–10 000 nests of grey-headed mollmawks, based on counts of nests in photograph montages of large colonies and ground counts of small colonies (Moore & Moffat 1990a).

4.3 GREY-HEADED MOLLYMAWK POPULATION CHANGES

Counts of nests in photographs of colonies at Courrejolles Isthmus and Hookers Finger in the 1940s and 1990s suggest that the grey-headed mollymawk population decreased by about 82–88% over 55 years. Intermediate estimates of nest numbers in the 1960s, 1970s and 1980s, and the decreasing number of nests found during ground counts in the 1990s, further suggest that the decline was continuous.

Poor breeding success during the 1940s may have produced crowded grey-headed mollymawk colonies if a high proportion of birds were breeding in successive years rather than following the normal biennial pattern. Poor survival of chicks at Courrejolles Isthmus was noted in 1943 and 1946, but 1945 was a good season (Sorensen 1944, 1947; Bailey & Sorensen 1962). Unfortunately, there is no information about breeding success in the years immediately preceeding the photographs. However, since three grey-headed mollymawk colonies were photographed in three different years (1942: MP1, MP2, MP4; 1943: JDK, 1-West, MP3a; 1945: MP1), it seems unlikely that they were all showing inflated occupancy. All the colonies had substantially larger nesting areas in the 1940s than the during the 1990s, and the lack of large tussocks indicates that the nesting areas had been occupied for many years previously.

At some colonies, such as Courrejolles Isthmus, the rate of decline slowed from 2.7% p.a. initially to 1.2% for the final decade, but small sub-colonies and peripheral nesting areas continued to disappear in the 1990s. During that decade, the numbers of nests of grey-headed mollymawks decreased at colonies both where they were in the majority and those where they were in the minority. This suggests that applying the rates of decline in the photographed colonies to the species as a whole is a valid method for estimating the population in the 1940s. With approximately 43 000 nests annually (Table 11), grey-headed mollymawks would have outnumbered Campbell mollymawks overall. However, for this to have occurred there must have been a greater decline overall at the northwestern colonies on Campbell Island, since grey-

headed mollymawks were in the minority at the Bull Rock colonies both during the 1940s (Sorensen 1943; Bailey & Sorensen 1962) and the 1990s. Alternatively, the main decline of grey-headed mollymawks occurred only at the photographed colonies.

Currently, grey-headed mollymawks tend to occupy steeper slopes than Campbell mollymawks or nest on the inland edge or ends of the same ledges. Campbell mollymawks nest in higher densities on the flatter ledges, which are more prevalent in the Bull Rock colonies. This may indicate a different nesting preference between the species, or that Campbell mollymawks arrive earlier at their main colonies and exclude the grey-headed mollymawks. Either reason would explain why grey-headed mollymawks may have congregated in their largest numbers at Courrejolles Isthmus and two Hookers Finger colonies during the 1940s. Some other neighbouring colonies may also have also been important for grey-headed mollymawks. For example, large numbers of birds may have occupied the extensive slopes of Courrejolles Peninsula, as unoccupied areas and colony fringes in the 1990s could have accommodated more birds. A decline in grey-headed mollymawk numbers at Courrejolles Peninsula could explain the overall (combined species) decrease in nest numbers and colony area that has occurred there since the 1960s. Similarly, at Hookers Peninsula, the patchy nest distribution and declining numbers of grey-headed mollymawk nests suggests that the species was much more numerous in the past. This supports the hypothesis that the northwestern colonies (Courrejolles to Hookers Peninsula) were more important for grey-headed mollymawks during the 1940s, and a smaller proportional change occurred at the northeastern colonies (Bull Rock and Eastern Colonies).

4.4 CAMPBELL MOLLYMAWK POPULATION CHANGES

Counts of nests in photographs of Bull Rock North suggest that the Campbell mollymawk population decreased by about 22% over 55 years between the 1940s and 1990s. Combining data from the 1995–97 ground counts and rates of change of nest numbers in photographs at Bull Rock North colony yielded an estimate of 31 300 Campbell mollymawk nests for all colonies in the 1940s (Table 11). Estimated numbers of nests had increased slightly by the 1960s, but then a 47% decline in numbers occurred, through the 1970s and 1980s, to approximately 19 300 nests. At this point a recovery began and there were 24 600 nests by 1995–97, still 6700 nests fewer than in the 1940s. Other photos from the 1960s–80s at Bull Rock South and Courrejolles Peninsula give supporting evidence for the pattern at Bull Rock North being representative of the whole island. However, the recent increase at Bull Rock North was more rapid than at other areas.

During the 1990s, the number of Campbell mollymawk nests showed an increasing trend at six of nine accessible colony areas. The exceptions were at Hookers Finger Colonies 2 and 5 and the Eastern Colonies, where there were small fluctuations in nest numbers from relatively high estimates in 1992. This may have been an artefact of the short data series or, alternatively, the species could be doing poorly at these colonies compared with others.

4.5 COMPARISON WITH OTHER STUDIES

The annual, adult survival of grey-headed mollymawks at Campbell Island in the 1990s was high (95.3%), breeding success was variable but low on average (40%) and recruitment was also low (16%, Waugh, Weimerskirch, Moore & Sagar 1999). This combination could drive a decline in the population, with adults not being replaced at a high enough rate. The modelled decline rate for grey-headed mollymawks on Campbell Island in the 1990s was 2.8% p.a. (Waugh, Weimerskirch, Moore & Sagar 1999), a finding which is supported by photograph and ground counts conducted during this study. Photograph counts suggested declines of around 2% p.a. overall, and of 5% for individual sectors of colonies. The Campbell Island demographics (Waugh, Weimerskirch, Moore & Sagar 1999) were similar to those found for grey-headed mollymawks at South Georgia (Prince et al. 1994; Croxall et al. 1998). Annual adult survival decreased since the early 1970s on South Georgia from 95% (assumed) to 93.4%, breeding success was variable and low on average (39%), and recruitment decreased, from 36% for the 1959–64 cohorts to < 5% for the 1982–86 cohorts, with a resulting decrease of 1.4%–1.8% p.a. (Croxall et al. 1998).

Grey-headed mollymawks have a widespread breeding distribution with no recorded geographical genotypes. This suggests that there is sufficient genetic mixing between populations to maintain homogeneity, a result of their widespread foraging and dispersal patterns (Burg & Croxall 2001). The existence of a good photograph series since the 1940s on Campbell Island is unique for studies of albatrosses around the world, as population baselines at other sites did not start until at least the 1960s–70s (Gales 1998; Croxall & Gales 1998). The decline demonstrated for the grey-headed mollymawk population on Campbell Island, beginning at least in the 1940s, combined with the similar demographic profile of birds on South Georgia (Croxall et al. 1998), home to 56% of the population (Stattersfield & Capper 2000), suggests a long-term decline occurred for the species as a whole. The current status of grey-headed mollymawk populations varies with location, but it is believed that the total population of about 250 000 birds is declining (Croxall & Gales 1998), and hence the species is listed as Vulnerable under IUCN Red List conservation criteria (Stattersfield & Capper 2000; Birdlife International 2003).

A demographic model produced from Campbell mollymawk banding data (1984–96) suggested a rate of population increase of 1.1% p.a. (Waugh, Weimerskirch, Moore & Sagar 1999), and this was supported by the photograph and ground counts conducted during the current study. Photograph counts at Bull Rock South, the same colony where banding studies were conducted, showed a 1% p.a. increase in nest numbers between the late 1980s and 1995–97, whereas the neighbouring Bull Rock North colony showed an increase of 3% p.a. (this study). Although the recruitment rate (19%) was relatively low on Campbell Island, the increase was generated by high adult survival (94.5%), high average breeding success (66%) and relatively early age at first breeding (10 years) compared with its closest relative, the black-browed mollymawk (*D. melanophrys*), on other islands (Waugh, Weimerskirch, Moore & Sagar 1999). For example, the black-browed mollymawk on South Georgia went from a probably stable or slightly increasing population in the 1970s to a 7% p.a. decrease in 1976–92 as a result of decreased annual adult survival (92.5%–91.5%), recruitment (27%–7%) and

breeding success (36%–18%). On the Kerguelen Islands average adult survival (90.6%), recruitment (14%), age at first breeding (10 years) and breeding success (63%) resulted in a slight overall decrease (0.2% p.a.) in 1979–95, although a 7% decrease in recruitment rate during the 1990s was apparently responsible for a steeper rate of decrease (Weimerskirch & Jouventin 1998).

The Campbell mollymawk is listed as Vulnerable under IUCN Red List conservation criteria because it is effectively restricted to one breeding location and has exhibited a substantial and recent decline (Stattersfield & Capper 2000; Birdlife International 2003). The worldwide population trends of the closely related black-browed mollymawk are complex and depend on the locality. For example, on South Georgia between 1977 and 1990, there was an approximately 10% overall increase in the population, although individual colony growth varied markedly from –77% to +96% (Prince et al. 1994). A more recent decrease in population size and breeding success on South Georgia was identified (Croxall et al. 1998; Prince et al. 1998). Similarly, the large Falkland Islands population, which comprises 70% of all black-browed mollymawks, was thought to be secure, but a substantial decline was reported in the late 1990s (Huin 2001). It has been inferred from this that the species may have declined overall in numbers by > 30% in the last 30 years, and it is also now regarded as Vulnerable (Birdlife International 2003).

The small numbers (30–100 birds) of black-browed mollymawk present on Campbell Island (Moore, Taylor, & Amey 1997; Moore, Burg et al. 2001) probably represent a spread of the species into the southwest Pacific over the last 50 years (Tennyson et al. 1998; Moore, Burg et al. 2001). Recent genetic work distinguished two forms (possibly subspecies or species) of *T. melanophrys*, one from the Falkland Islands and the other from Diego Ramirez, South Georgia and Kerguelen islands (Burg & Croxall 2001). Both forms occur on Campbell Island, and interbreed with Campbell mollymawks (Moore, Burg et al. 2001).

4.6 REASONS FOR POPULATION CHANGES

Shooting and catching albatrosses for sport and amusement, as well as for food, was a major pastime on ships in the 19th century (Medway 1998). The main routes for passenger ships from Australasia to Britain looped through the New Zealand subantarctic, and as many as 93 ships brought immigrants to New Zealand during the peak traffic between 1874–75 (Medway 1998). Some ships caught large numbers of birds, up to 12 per day in one case (Medway 1998), during a journey which typically took 3 months. Wandering albatrosses and black-browed albatrosses were probably the most vulnerable to being captured (Medway 1998; Tickell 2000), but it is not known to what extent this mortality affected populations in the New Zealand region.

Direct exploitation of albatrosses at their breeding islands affected many northern hemisphere populations in the late 19th century. For example, the combined effects of feather hunters and volcanic eruptions drove the abundant short-tailed albatross (*Phoebastria albatrus*) close to extinction (Gales 1998). Exploitation did not occur to the same extent in the New Zealand subantarctic, and was short-lived. Mollymawk eggs were collected on Campbell Island during its farming era (1895–1931), and possibly earlier by sealers, because 'they were good to eat too, bigger than a goose egg' (Kerr & Judd 1978).

Animals introduced to Campbell Island probably had a more long-term influence. Norway rats (*Rattus norvegicus*) were abundant by 1868 and largely wiped out all but the large seabirds. They apparently only scavenged in mollymawk colonies, as they could not break into the relatively large mollymawk eggs (Taylor 1986). Cats (*Felis catus*) may have had more of an impact, although they were always scarce (Dilks 1979) and had apparently died out by the 1990s (Moore 1997; confirmed in 1999 by searching with a dog, S. Theobold pers. comm.). When the farm ceased operating in 1931 (Kerr 1976) the remaining sheep became feral and continued to degrade the vegetation and landforms. Sheep were attracted to the mollymawk colonies by the lush growth of grasses. While grazing, they forced adults from their nests which exposed the eggs to brown skua (*Stercorarius skua lonnbergi*) predation (Westerskov 1960), and chicks fell from their nest pillars and died (Sorensen 1951). Disturbance by sheep was eliminated in 1970 when a fence was constructed across Campbell Island and all the sheep in the northern part were shot (Dilks & Wilson 1979).

Natural predators such as brown skua may get out of balance with their prey during a declining phase. For example, if larger proportions of grey-headed mollymawks are at the edge of colonies or in small low-density sub-colonies, skuas may be able to prey easily on the species' eggs and chicks. This appears to be the case for rockhopper penguins (*Eudyptes chrysocome*) on Campbell Island where skuas are very active predators at steadily declining colonies (P.J.M. pers. obs.). In a similar way, a high level of predation by great skuas (*S. skua*) is believed to be hastening the decline of kittiwakes (*Rissa tridactyla*) in Shetland (Heubeck et al. 1999).

The impact of fishing activities on the food supply or survival of albatrosses has been highlighted as a major problem in recent years. Brothers (1991) estimated that 44 000 albatrosses, including 19 250 black-browed and 1375 grey-headed mollymawks, were killed annually in the southern oceans by the Japanese tuna long-line fishery. On the Kerguelen Islands, the decline in the black-browed mollymawk population may have been a consequence of trawling operations, which killed large numbers of birds (Weimerskirch et al. 1987). Similarly, 44% of black-browed mollymawks which were banded on South Georgia and recovered off South Africa were trapped in fishing gear, and probably many of these were killed for food by fishermen, as formerly many were sold in Cape Town markets (Morant et al. 1983). Long-lining off the coasts of South America (Neves & Olmos 1998) and Southern Africa (Ryan et al. 2002) also killed large numbers of seabirds, up to 30 000 per year in the latter area, including 21 000 albatrosses. Overfishing is also a threat to albatross species, for example black-browed albatrosses in the Falkland Islands make extensive use of commercially taken fish and squid (Thompson & Rothery 1991) so prey depletion could have long-term effects (Thompson & Riddy 1995). In contrast, for some species, or areas, fishing trawlers may be of benefit, at least in the short term, by providing an easy source of fish waste to scavenge (Thompson & Rothery 1991; Thompson & Riddy 1995; Prince et al. 1998; Sagar et al. 1999).

The increase in the black-browed mollymawk population on South Georgia in the 1980s was possibly a result of scavenging opportunities offered by fishing trawlers and the lack of long-lining in the region, or in the non-breeding foraging areas (Croxall et al. 1998; Prince et al. 1998). The more recent decrease in numbers and breeding success was thought to be a result of the new

Patagonian toothfish fishery (Croxall et al. 1998; Prince et al. 1998), illustrating that new threats to albatrosses can appear at any time. Similarly, the recently identified decline at the Falkland Islands was probably linked to the development of new long-line fisheries in the area (Huin 2001).

The decline of Campbell mollymawks throughout the 1960s–80s was similar in timing and nature to that for the wandering albatross at Possession Island (Crozet Islands) in the Indian Ocean (Weimerskirch et al. 1997). The wandering albatross population decreased 54% between 1970 and 1985 and subsequently began to recover. The decline resulted from increased adult and juvenile mortality which coincided with a peak in long-line fishing near the Crozet Islands (Weimerskirch et al. 1997). A large-scale southern bluefin tuna fishery in the Australasian region peaked in New Zealand waters in 1971–83 (Murray et al. 1993). The Campbell mollymawk (both adult and juvenile) was a major component of incidental bycatch in New Zealand waters (Murray et al. 1993). Black-browed mollymawks were also a major component of bycatch in Australian waters (Klaer & Polacheck 1997), with over 1500 estimated as killed each year and half the birds identified were Campbell mollymawks (Gales et al. 1998). Presumably this fishing-related mortality contributed to the decline in breeding numbers on Campbell Island. The steepness of the decline at Bull Rock North on Campbell Island could only be a result of high adult mortality (Waugh, Weimerskirch, Moore, & Sagar 1999). Subsequently, fishing effort in the Australasian region decreased (Murray et al. 1993; Klaer & Polacheck 1997) and, recently, mitigation measures have attempted to limit seabird bycatch, at least by the domestic fleets of New Zealand and Australia. An analysis of long-line bycatch in New Zealand in the early 1990s found that the numbers of mollymawks caught was variable, and fewer than 190 birds (of all species combined) per year were caught in the New Zealand EEZ (Manly et al. 2002). Perhaps further illustrating an improved situation, the total number of Campbell mollymawks caught by observed vessels in New Zealand fisheries decreased from 45 in 1996 to 2 in 2001 (Robertson et al. 2004).

The decline in grey-headed mollymawks at South Georgia during the 1980s was thought to be most probably a result of fishing bycatch (Croxall et al. 1998). Grey-headed mollymawks are found less frequently associated with fishing boats than black-browed mollymawks, but their wide distribution, particularly at the non-breeding stage, could make them more vulnerable to accidental capture by pelagic long-liners (Prince et al. 1998; Waugh, Weimerskirch, Moore, & Sagar 1999). Grey-headed mollymawks are accidentally caught on tuna long-lines in Australasian waters (Murray et al. 1993; Klaer & Polacheck 1997) and in some fishing trips in deep water off Australia 37%, of the albatrosses caught were grey-headed mollymawks (Prince et al. 1994). However, no grey-headed mollymawks were caught on observed vessels in New Zealand waters in 1996–2001 (Robertson et al. 2004).

Although possibly a contributing factor, the mortality caused by long-line fisheries is unlikely to have been the primary cause of the grey-headed mollymawk decline on Campbell Island (Waugh, Weimerskirch, Moore, & Sagar 1999). Although the Japanese southern bluefin tuna long-line fishery developed as early as the mid 1950s around New Zealand and effort accelerated through the 1960s (Tuck et al. 2001), the peak in the Australasian region did not occur until the 1970s–80s (Murray et al. 1993; Tuck et al. 2001). At least half the

decrease in grey-headed mollymawk numbers occurred by the 1960s and the decline appears to have been continuous over 55 years. In contrast, the Campbell mollymawk did not show a decrease in numbers until after the 1960s, and these changes were more closely in parallel with the changes in long-line fishing effort in the region.

Because of the long-term and continuous nature of the decline, it is more likely that environmental changes (either natural or anthropogenic) have affected the grey-headed mollymawk population. Seabird populations fluctuate naturally in concert with environmental fluctuations, yet short-term studies may not encompass the full ebb and flow of the population. It is possible, for instance, that grey-headed mollymawks rose to a peak in numbers during the 1940s, and then gradually decreased. Humans have had major effects on marine food chains in the last 150 years through hunting, fishing, pollution, and global warming (Duffy 1994). Albatross populations, with individuals that live 50 years or more, may take decades to decline or recover from environmental perturbations. Even though a 55-year span of photograph counts is a relatively long time-scale for seabird studies, it may shed light on only a small part of a longer-term fluctuation in albatross numbers.

Changes in food supply undoubtedly have important effects on seabird populations. Huge amounts of food are required to maintain breeding populations of thousands of birds. It was estimated, for example, that 13 million tonnes of food per year were taken by seabirds and seals from the seas around South Georgia, including 64 000 tonnes by 240 000 mollymawks (Croxall et al. 1985). Hence, the dramatic reduction by humans of whale and seal numbers in southern oceans must have had profound effects on other sea life. For example, a krill surplus was thought to be the reason for the expansion and increase in chinstrap penguins (*Pygoscelis antarctica*) (Croxall & Prince 1979; Croxall 1992). Another example was the Southern elephant seal (*Mirounga leonina*) on Macquarie Island. Numbers had increased after the end of sealing to reach a peak in the 1940s, but then declined by 44% (Hindell & Burton 1987). Hindell & Burton (1988) suggested that an overshoot in population level could have been caused by exploitation of an abundant food supply available at the end of the sealing era, and the decline was a return to equilibrium. The small population of elephant seals on Campbell Island, an offshoot of the larger Macquarie Island population, also showed a similar increase from zero (having probably been exterminated by sealers), to a peak of > 100 pup births/yr in the 1940s, and a decline to < 10 births/yr in the 1980s (Sorensen 1950; Taylor & Taylor 1989; Moore & Moffat 1990b).

The food surplus theory has been challenged. Although chinstrap penguins increased, the closely related Adelie penguin (*P. adeliae*) did not. The effect of global warming on the sea ice was proposed as an alternative explanation for the population trends (Fraser et al. 1992). Oceanic warming and its effect on the food supply was also implicated in the 90% decline of the rockhopper penguin population at Campbell Island from over one million birds in the 1940s to 100 000 birds in the 1980s (Moors 1986; Cunningham & Moors 1994). This decline continued through the 1990s (P.J.M. pers. obs.).

Three unrelated Campbell Island species (grey-headed mollymawk, rockhopper penguin and elephant seal) have all shown similar population declines of 80–

90% since the 1940s. All three species feed pelagically. For rockhopper penguins it was suggested that the shift south of the subantarctic convergence zone made good krill foraging zones unattainable during the breeding season. This resulted in the rockhoppers feeding on less-favoured fish species which, in turn, reduced the body condition required for the birds to breed and moult (Cunningham & Moors 1994). However, rather than a food switch occurring, stable isotope analysis of feathers from museum specimens collected between 1880 and 1980 showed evidence of a food decrease, the result of primary productivity declining since the 1940s (Thompson & Sagar 2002). Grey-headed mollymawks on Campbell Island and elsewhere feed mainly on squid in oceanic waters (Weimerskirch et al. 1988; Prince & Francis 1984; Waugh, Weimerskirch, Cherel et al. 1999). Waugh, Weimerskirch, Moore, and Sagar (1999) suggested that the decline of the grey-headed mollymawk population on Campbell Island might be a result of long-term changes in the squid stocks in oceanic waters. This may, in turn, have been caused by the decrease in productivity of the oceans near Campbell Island (Thompson & Sagar 2002).

In contrast to the above pelagic feeders, some species which feed over continental shelf areas are stable, fluctuating, or increasing in number on Campbell Island. For example, yellow-eyed penguins (*Megadyptes antipodes*), which feed mainly on bottom-dwelling fish close to their breeding areas (Moore & Wakelin 1997), decreased in number between 1988 and 1992 but subsequently increased (Moore, Fletcher, & Amey 2001). Southern royal albatrosses (*Diomedea epomophora*) appear to have increased through the 20th century, possibly recovering from depredations during the farming era of 1895–1931 (Moore, Scott et al. 1997). This species feeds during the breeding season mainly over the Continental Shelf edge in the New Zealand region, and during the non-breeding season, off the coast of South America (Imber 1999). Similarly, Campbell mollymawks, apart from the decline in the 1960s–80s, have generally shown stable or increasing numbers. They, and the closely related black-browed mollymawk, feed mainly in more productive waters over continental shelves (Stahl et al. 1985; Weimerskirch et al. 1986, 1988; Waugh, Weimerskirch, Moore, & Sagar 1999), but Campbell mollymawks will feed on squid on longer trips to the Polar Front (Waugh, Weimerskirch, Cherel et al. 1999). Presumably this foraging strategy has been less affected by the oceanic changes than that of pelagic species such as the grey-headed mollymawk.

4.7 CONSERVATION ACTIONS

Efforts to restore the natural values of Campbell Island have been underway since 1954, when it was declared a reserve for the preservation of flora and fauna. It later became a national nature reserve (Anon. 1983, 1998a). An important step was the gradual eradication of sheep in 1970s–90s (Dilks & Wilson 1979; Anon. 1998a; A. Cox pers. comm.). Norway rats were eradicated in 2001 (McClelland & Tyree 2002; King 2003), opening the way for return of seabirds and landbirds, many of which were wiped out by cats and rats in the 19th century. The Department of Conservation (DOC) also limits access to the island and manages the threats of introduced weeds and pests (Anon. 1998a).

Momentum is gathering in the co-operative efforts of government and fishers to limit the amount of seabird bycatch, since the problem was first highlighted in the 1990s (Brothers 1991; Alexander et al. 1997). Through a slow process of education, negotiation, and experimentation in New Zealand (e.g., Molloy et al. 2000), there has already been an attitudinal shift among fishers towards safe environmental practices, and an enthusiasm for taking on the challenge of catching fish without harming seabirds (Crysell 2002; Hilhorst 2002). The New Zealand fishing industry also aims to create sustainable, well-managed fisheries, for example, the recent certification of the hoki fishery by the international Marine Stewardship Council includes a commitment to address the issue of bycatch (Northcott 2002). A further challenge will be extending these changes to other fishing nations, especially those that operate on the high seas.

Mitigating anthropogenic effects is an urgent task for all nations (Anon. 1998b). A global temperature rise of between 1°C and 3.5°C is predicted this century, with an associated rise in sea level of 1 m–2 m and significant effects on the world's biota (Anon. 1992; Malamud 1997). These changes could affect seabird populations, as was suggested by the link between decline of the rockhopper penguin population on Campbell Island and periods of warmer sea surface temperature (Cunningham & Moors 1994).

The New Zealand government is party to a variety of conventions and agreements on the environment: for example, the Convention on Biological Diversity, The Rio Declaration and The Kyoto Protocol to the Framework Convention on Climate Change (Dunningham 1998), and the Convention on the Conservation of Antarctic Marine Living Resources (Anon. 1992). Highlighting the importance of the New Zealand subantarctic islands as a World Heritage Site is part of that process (Anon. 1997).

Whether these international agreements can slow the deleterious effects of human population growth is another matter, as they rely on the goodwill of all governments of the world to work towards the same goals. The limited progress and lack of unanimity at the 2002 World Summit on Sustainability illustrated this problem. As Duffy (1994) noted, although the concept of sustainable development is popular, no natural environment can sustain an ever-increasing human population.

5. Recommendations

5.1 NATIONAL AND INTERNATIONAL CONSERVATION INITIATIVES

It is important to monitor the populations of mollymawks of Campbell Island, as well as other seabirds, both threatened and common. They are indicators of the health of the nature reserve as well as the Southern Ocean ecosytem. The longer history of monitoring on Campbell Island compared to other New Zealand subantarctic islands presents an opportunity to build on existing baselines. A suite of species, e.g. Campbell and grey-headed mollymawks, southern royal

albatross, light-mantled sooty albatross (*Phoebetria palpebrata*), rockhopper and yellow-eyed penguins, could be studied to track population trends, as well as illustrate the potential effects of fishing interactions or temperature change. At the same time, the recolonisation of the island by smaller seabirds, e.g. burrowing petrels such as sooty shearwaters (*Puffinus griseus*), in the absence of rats should be monitored.

Emphasis should be given to a multi-disciplinary approach, perhaps collaborating with National Institute of Water and Atmospheric Research Ltd (NIWA) programmes investigating the functioning of the southern ocean ecosystem (which may affect seabird foraging).

The author recommends that DOC strongly promotes international efforts to halt and reduce negative effects of humans on the environment. Declines in species on Campbell Island could be used to help illustrate the potential linkages.

5.2 ANNUAL MONITORING

Interpretation of short-term and long-term population fluctuations is made significantly easier by annual monitoring. Fishing activity can change within a matter of months, and large declines in albatross populations can occur within a 5-year timeframe. To date, most monitoring of birds on Campbell Island has been undertaken as part of science and research investigations similar to this report. However, it is unlikely that Southland Conservancy (which administers Campbell Island, on behalf of DOC) could undertake basic regular monitoring of seabirds, given current and predicted resource levels (C. West, pers. comm.). The author recommends that DOC seek other funding to increase the level and frequency of monitoring of seabirds.

5.3 DECADAL MONITORING

As a minimum monitoring regime for mollymawks on Campbell Island, ground counts should be conducted for three consecutive years every decade. The next 3-year period would be 2005/06 to 2007/08. Ground counts of accessible colonies should be conducted and photographs taken of inaccessible areas. Based on previous experience, it would take three people two weeks to complete the census.

Extra time would be required for a more comprehensive, multi-species programme, which should include assessments of population size, structure and dynamics, and foraging.

If resources cannot be dedicated to regular mollymawk ground counts, at the very least, all photographs from the standard photopoints should be repeated in mid-October for three consecutive years every decade. One fine calm day is required for the main colonies, and it may take two weeks for the ideal light and weather conditions to allow the photography of Courrejolles Peninsula. Additional resources would be required for printing photographs, counting mollymawks in the photographs, data analysis and writing up.

5.4 COUNT METHODS

Count methods and count areas should follow Moore (1999) and Moore & Blezard (1999a). Photopoint marker pegs require checking and replacing if necessary. Ground counts should be conducted by a combination of nest visit counts, ledge counts and binocular views across, depending on the terrain, and utilising the experience gained from the 1995–97 surveys. Ledge counts can be very difficult to conduct in large areas without landmarks, so it is recommended that nest visit counts be conducted at these areas and ledge counts at the narrower ledges. Views down, binocular views down, and telescope counts should only be used at inaccessible colonies.

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Appendix 1

REGRESSION LINES OF COUNTS OF MOLLYMAWK NESTS ON CAMPBELL ISLAND

TABLE A1.1 SUMMARY OF REGRESSION LINES OF PHOTOGRAPHS COUNTS OF NESTS (EXPRESSED AS PERCENTAGE OF MID-OCTOBER COUNT) FOR PHOTOGRAPHS OF MOLLYMAWK COLONIES TAKEN BETWEEN SEPTEMBER–DECEMBER AND JANUARY–APRIL DURING THE 1987 AND 1991–97 BREEDING SEASONS.

PHOTOPOINT*	COUNT ZONE SUBTOTAL	SEPTEMBER–DECEMBER		JANUARY–APRIL	
		REGRESSION LINE	R^2	REGRESSION LINE	R^2
Grey-headed mollymawk-dominated colonies					
MP1	T8	–0.4355x + 224.51	0.5606	–0.2284x + 122.56	0.3485
MP2	T13	–0.1744x + 149.24	0.2139	–0.3968x + 207.98	0.756
MP3a	T17/18	–0.2556x + 174.01	0.2443	–0.2947x + 158.55	0.5639
MP3b	T21	–0.2726x + 175.3	0.2619	–0.0733x + 67.768	0.0325
MP4	T24	–0.3231x + 191	0.2557	–0.1987x + 123.27	0.1341
MP8/9	T29/31	–0.3857x + 210.96	0.522	–0.2695x + 143.57	0.4552
Total		–0.3144x + 189.55	0.3384	–0.2486x + 138.84	0.3059
Campbell mollymawk-dominated colonies					
MP5	T5c,25	–0.0786x + 122.1	0.0689	–0.605x + 297	0.8266
MP5d	T5d	–0.256x + 171.84	0.6716	–0.1715x + 92.016	0.3675
MP6	T26	–0.201x + 155.3	0.4178	–0.4657x + 241.36	0.534
MP7	T27	–0.2013x + 156.01	0.376	–0.479x + 246.07	0.7845
MP10/12	T34/35/49/50	–0.1185x + 133.31	0.2622	–0.7569x + 367.56	0.8742
Total		–0.1468x + 141.39	0.2782	–0.6431x + 317.98	0.7748

* Data are presented for individual photopoints or combined for the same colony as well as overall data for colonies dominated by grey-headed mollymawk (Fig. A1.1) or Campbell mollymawk (Fig. A1.2).

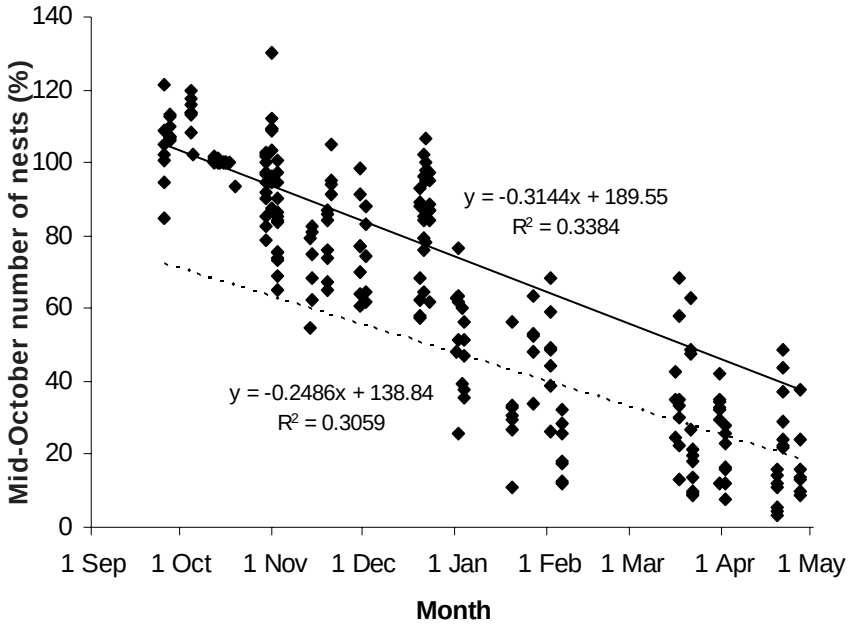

Figure A1.1. Photograph counts of nests at colonies dominated by grey-headed mollymawks at different times of the breeding season in 1987 and 1991–97, expressed as percentages of the mid-October counts. Regression lines are fitted for October–December (solid line) and January–April (dotted line).

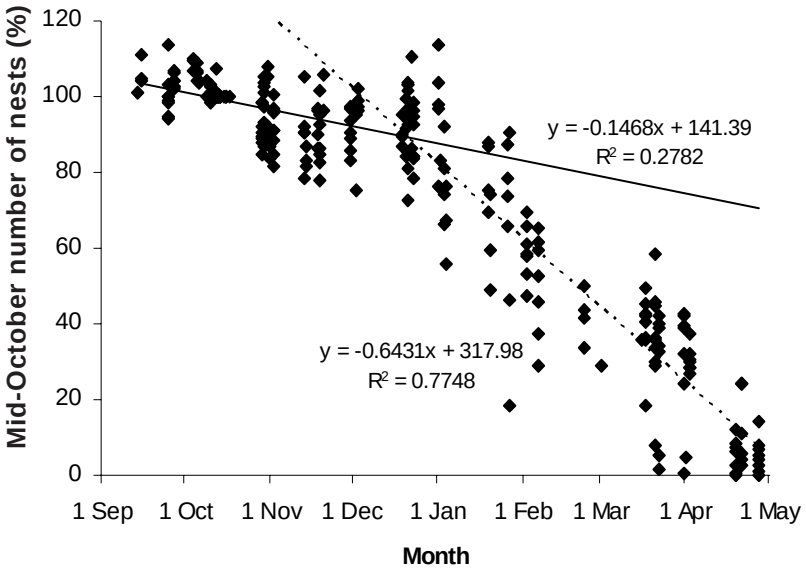

Figure A1.2. Photograph counts of nests at colonies dominated by Campbell mollymawks at different times of the breeding season in 1987 and 1991–97, expressed as percentages of the mid-October counts. Regression lines are fitted for October–December (solid line) and January–April (dotted line).

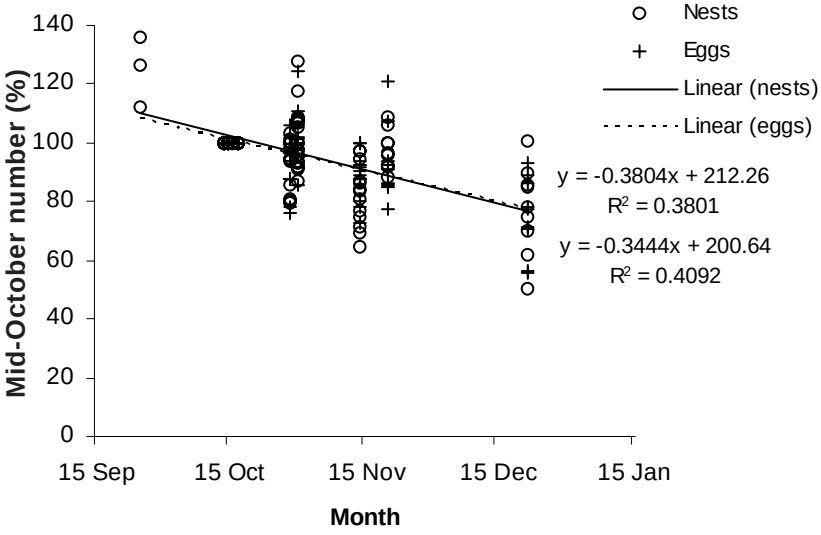

Figure A1.3. Regression lines for ground counts of eggs and nests at colonies dominated by grey-headed mollymawks at different times of the breeding season in 1995–97, expressed as percentages of the mid-October counts.

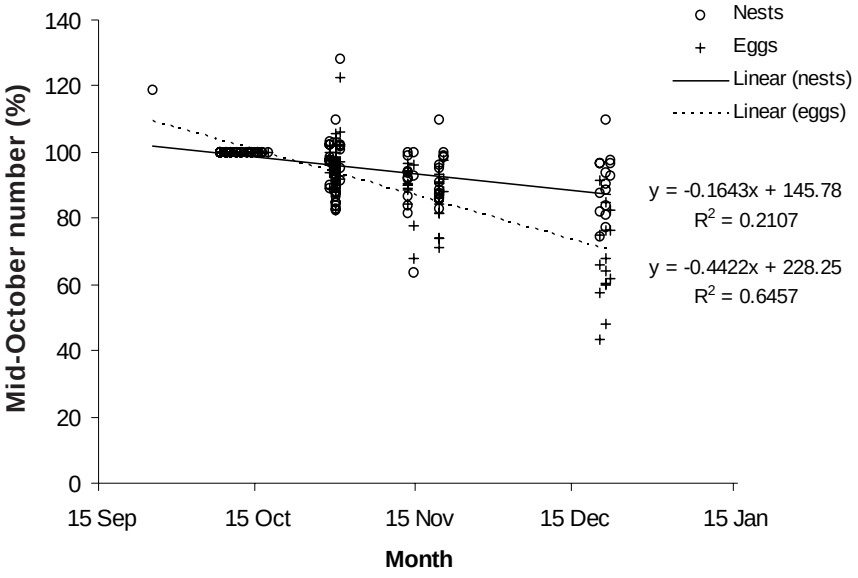

Figure A1.4. Regression lines for ground counts of eggs and nests at colonies dominated by Campbell mollymawks at different times of the breeding season in 1995–97, expressed as percentages of the mid-October counts.

Appendix 2

COMPARISON OF COUNTS AND BREEDING SUCCESS

Comparison of trends in photograph counts, ground counts, and/or breeding success in mollymawk colonies on Campbell Island.

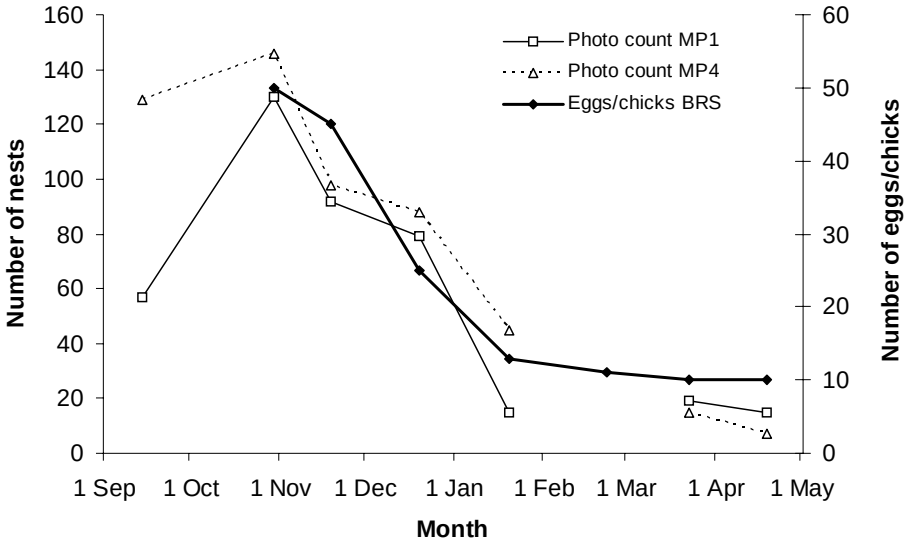

Figure A2.1. Comparison of trends in photograph counts at grey-headed mollymawk-dominated colonies (Courrejolles Isthmus—MP1, Hookers Finger 3—MP4) with breeding success of grey-headed mollymawk nests at Bull Rock South (BRS) during the 1987 breeding season.

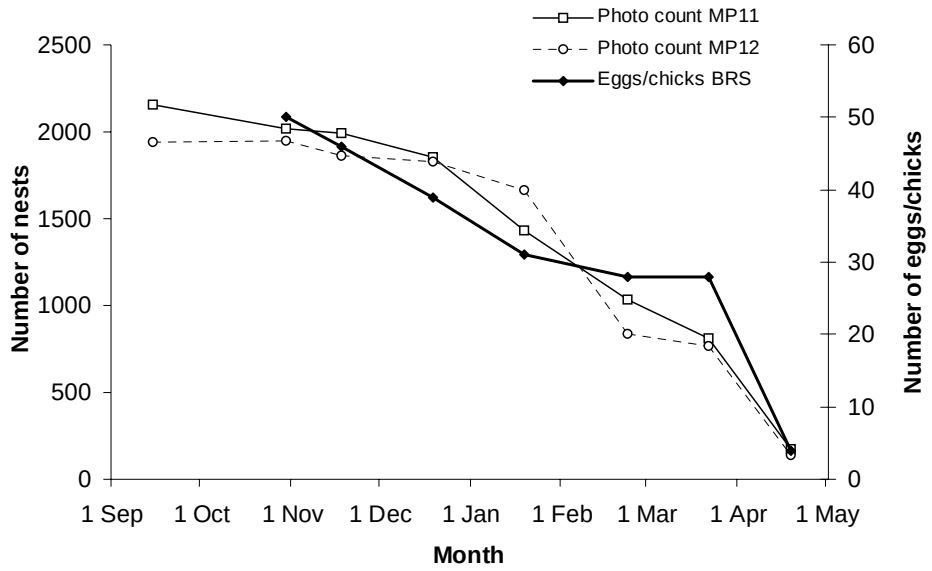

Figure A2.2. Comparison of trends in photograph counts at Campbell mollymawk-dominated colonies (Bull Rock North—MP11, Bull Rock South—MP12) with breeding success of Campbell mollymawk nests at Bull Rock South (BRS) during the 1987 breeding season.

Figure A2.3. Comparison of trends in photograph counts at grey-headed mollymawk-dominated colonies (Courrejolles Isthmus—MP1, Hookers Finger 3—MP4) with breeding success of grey-headed mollymawk at Courrejolles Isthmus (all nests in JDK subcolony) and Bull Rock South (BRS) during the 1991 breeding season.

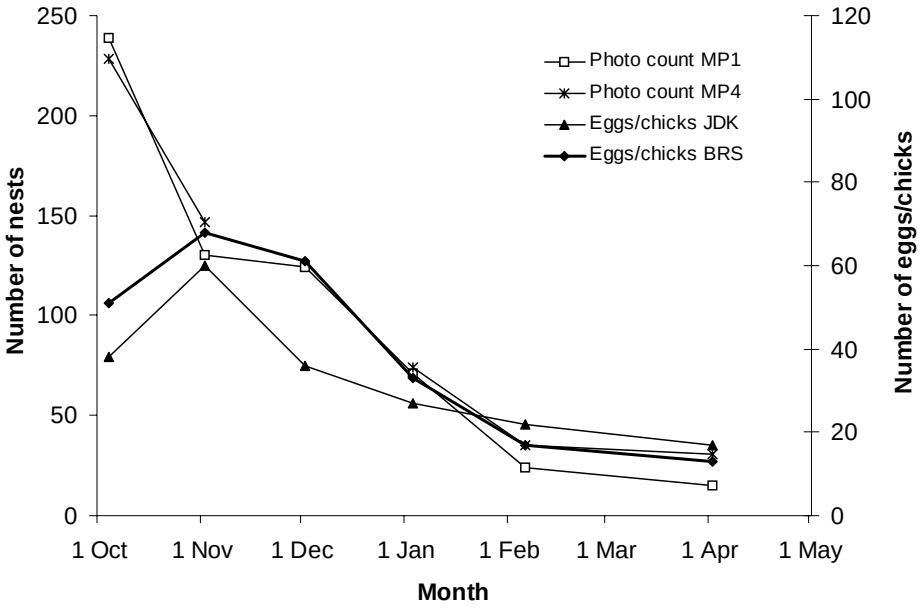

Figure A2.4. Comparison of trends in photograph counts at Campbell mollymawk-dominated colonies (Bull Rock North—MP11, Bull Rock South—MP12) with breeding success of Campbell mollymawk nests at Bull Rock South (BRS) during the 1991 breeding season.

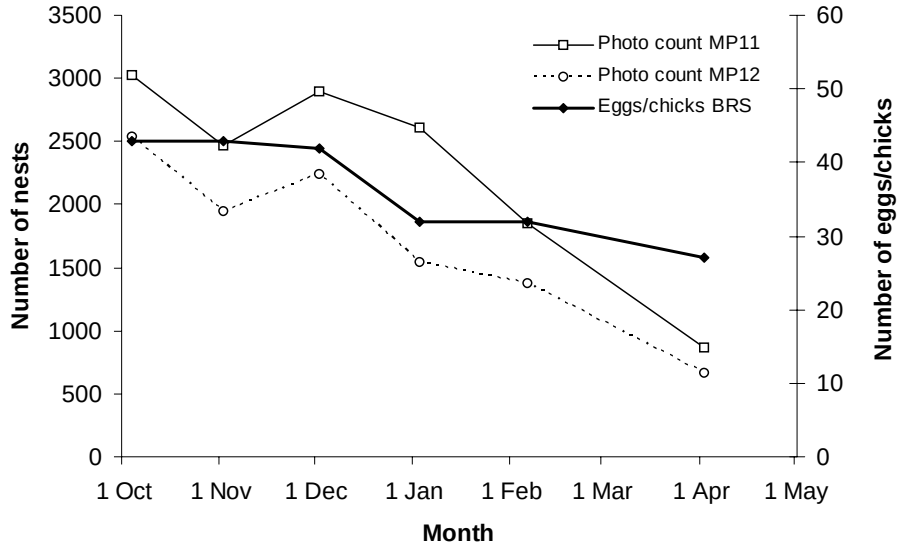

Figure A2.5. Comparison of trends in photograph counts (MP3b) with nest visit ground counts at Hookers Finger Colony 3 during the 1995 breeding season.

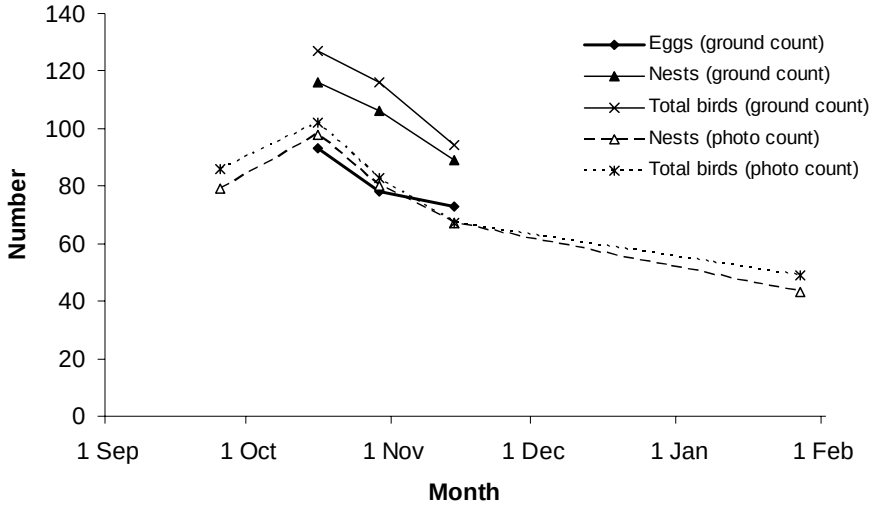

Figure A2.6. Comparison of trends in photograph counts (MP5d) with nest visit ground counts (HF5d) at Hookers Finger Colony 5d during the 1995 breeding season.

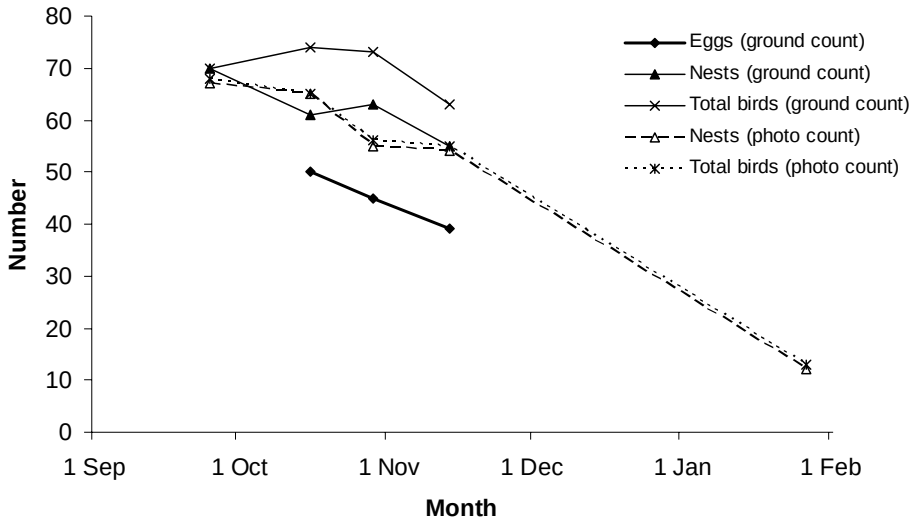

Figure A2.7. Comparison of trends in photograph counts (MP12 zones 9, 12) with nest visit ground counts at Bull Rock South (zones 9, 12) during the 1995 breeding season. The photopoint has an oblique view of the ledges.

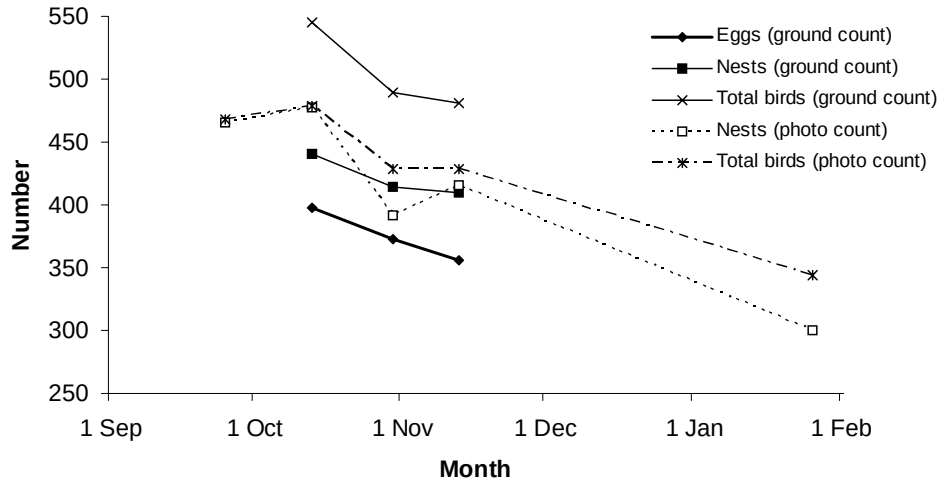

Figure A2.8. Comparison of trends in photograph counts (MP12 zones 9, 12) with nest visit ground counts at Bull Rock South (zones 9, 12) during the 1996 breeding season. The photopoint has an oblique view of the ledges.