47 The effects of human activity and environmental variability on long-term changes in Adélie penguin populations at Palmer Station, Antarctica

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ABSTRACT

To assess whether human activities due to tourism were negatively impacting Adélie penguins (*Pygoscelis adeliae*), we compared long-term population trends at visited and control sites on Torgersen Island considering underlying factors associated with environmental variability. To this end, a hillshade model of Torgersen Island was developed; linear regression and discriminant function analyses were used to examine breeding population/landscape interactions.

Results suggest that variability in population trends on Torgersen Island are forced primarily by colony aspect and colony area. Colonies with south-facing aspects are decreasing faster than colonies with north-facing aspects. Smaller colonies are decreasing faster than larger colonies. Both trends are likely due to interactions between the effects of increased snow deposition and decreasing egg and/or chick survival due to predation and flooding.

To examine human influences, subsequent analyses were standardised by pairing Adélie penguin colonies according to area and aspect on the visited and control sides of Torgersen Island. Tourism appears to have no detectable impact on Adélie penguin breeding population size or breeding success; comparisons between population trends in visited and control sides of the island were either not significant or inconsistent with site-specific tourist visitation patterns.

Key Words: Antarctica, Palmer Station, Adélie penguin, human impacts, tourism, landscape effects, population trends

INTRODUCTION

Human activity, and tourism in particular, has steadily increased on the Antarctic Peninsula over the past 25 years (Enzenbacher 1992, Cobley *et al.* 2000). The potential effects that tourism may have on wildlife populations have thus become an important conservation issue that in Antarctica is uniquely magnified because the activities of both humans and wildlife tend to converge on a small fraction of the coastal landscape that is free of ice. This obligatory link between penguins, proximity to marine resources and terrestrial nesting habitat may further amplify interactions with humans. As a result, the spatial scales over which wildlife-tourist interactions occur tend to be relatively small, but may involve repeated visits to the same sites by hundreds to thousands of tourists over the course of a single season. One concern, therefore, is that the intense human activity associated with these sites will negatively impact wildlife populations.

Coincident with the increasing concern about possible human impacts on wildlife populations is a growing controversy regarding cause and effect. Although some studies have concluded that human activity has adverse effects on wildlife (Reid 1968, Culik *et al.* 1990, Wilson *et al.* 1990, Woehler *et al.* 1994, Giese 1996), other studies do not support these conclusions. A study by Fraser & Patterson (1997), for example, demonstrated that there was no correlation between long-term Adélie penguin population changes in the vicinity of Palmer Station, western Antarctic Peninsula, and the human use histories of area rookeries. Similar findings are described in a study by Cobley *et al.* (2000) on tourist impacts at Port Lockroy, western Antarctic Peninsula. This study demonstrated that Gentoo penguins (*Pygoscelis papua*) not only increased dramatically in the area despite the presence of thousands of annual visitors, but also exhibited no significant differences in reproductive success between visited and unvisited control sites. Comparable results have also been reported by Stonehouse (1965) and Taylor *et al.* (1990), who observed that long-term variability in Adélie penguin breeding populations followed

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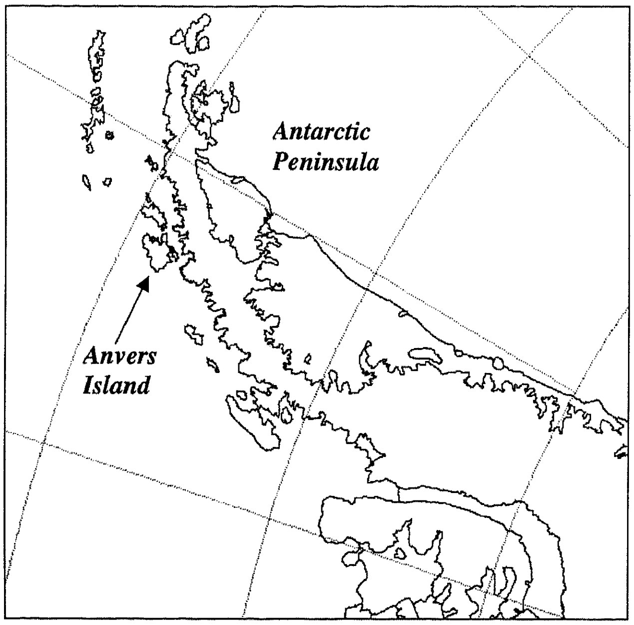

Fig. 1. Antarctic Peninsula and Anvers Island

similar trends in areas where human activity was prevalent and where it was absent.

To the extent that cause and effect remains a controversial issue in human impact studies, there is an emerging consensus that the issue will not be adequately resolved until we further our understanding of the underlying factors responsible for natural population variability (Woehler *et al.* 1994). Indeed, recent studies that adopted this approach have shown that a significant, but previously unrecognized, source of population variability in Adélie penguins is due to interactions between breeding habitat geomorphology and changing patterns of snow deposition (Fraser & Patterson 1997, Patterson 2001). These findings are directly relevant to human impact studies because the implication is that by isolating this natural "landscape" effect on population variability, it may be possible to tease out effects that might be induced by tourism. This landscape effect is linked conceptually to Pulliam's (1988) work on habitat-specific demography in that it utilizes the idea that breeding habitat quality can drive local-scale changes in populations that are independent of factors such as human activity.

The main objectives of this study were to develop and apply a landscape model to examine whether the effects of tourist activities on population trends could be detected above the natural variability induced by habitat geomorphology (cf. Fraser & Patterson 1997). We systematically examined and identified habitat specific features linked to breeding success. The effects of human visitation patterns on Adelie penguin populations were then considered within the context of this landscape perspective. Palmer Station (Fig. 1) has been a popular tourist destination for nearly 30 years, and historically has been divided into areas where visits by tourists are permitted and areas where they are not (Fig. 2). This provided an ideal experimental setting to examine Adélie penguin population responses with and without the addition of tourist activities.

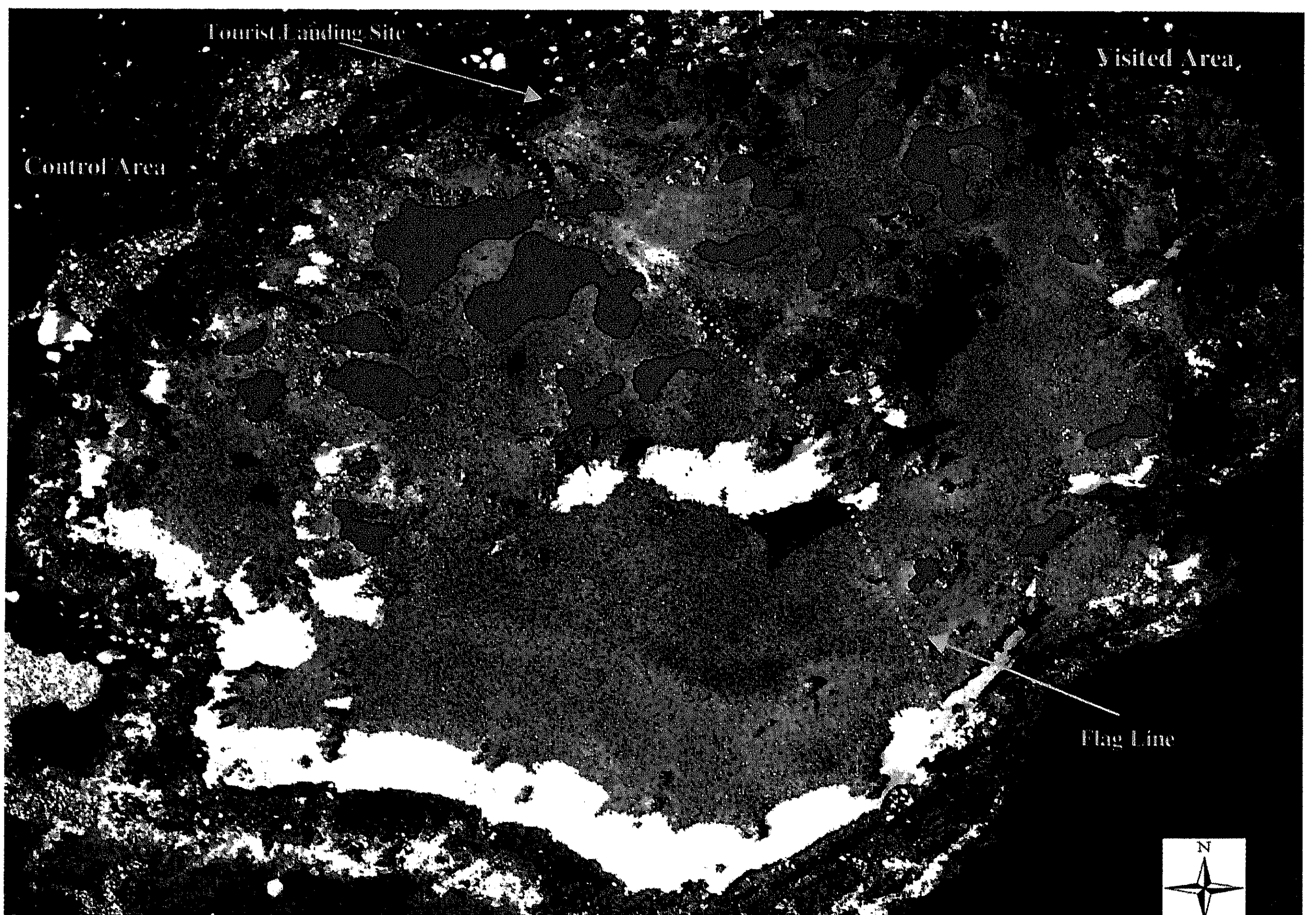

Fig. 2. Aerial photograph of Torgersen Island illustrating the division between visited and unvisited Adélie penguin colonies

METHODS

Study Area

The study was conducted on Torgersen Island (64°46'S, 64°04'W, Fig. 2), where tourists have been visiting a large Adélie penguin rookery (ca. 8000 breeding pairs) for nearly three decades. Torgersen Island is 500m in diameter, relatively flat (maximum height above mean sea level is 17m), and is bisected by a low-lying, east-west ridge that roughly divides the island into areas of predominantly north or south aspects.

To examine Torgersen Island's terrestrial habitat, a Digital Terrain Model (DTM) was developed for the island using low-altitude (450m) aerial photographs taken during the 1998/99 season. The aerial photographs were geo-rectified using static ground GPS surveys (Sanchez 1999); the resulting DTM was then used to create a hillshade model of Torgersen Island. The hillshade model shown in Figure 3 illustrates a gradient of habitat quality with a white to black scale indicating areas on the island receiving the least and most amounts of snow, respectively. We used this model to examine interactions between

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Fig. 3. Hillshade model of Torgersen Island. The coloured areas represent Adélie penguin colonies. The transition from light to black shading represents gradients in landscape aspect; lighter areas are north-facing and are typically scoured free of snow by predominant winds

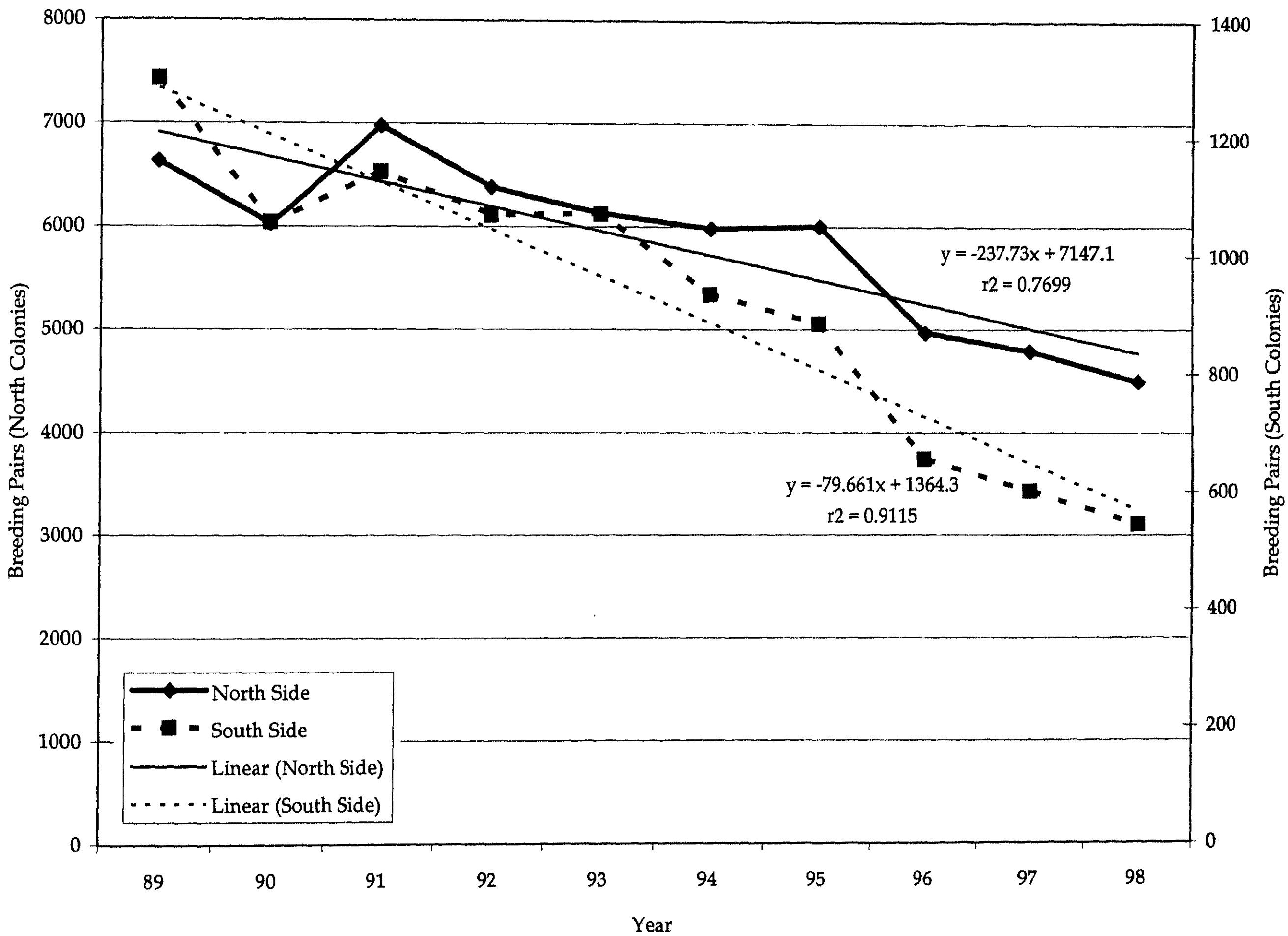

Fig. 4. Adélie Penguin Breeding Population Trends on the North and South Sides of Torgersen Island. Note that two y-axes are used to represent breeding populations on the north and south sides of Torgersen Island. Over the ensuing 10-year period, north colonies decreased by 32% versus 58% for the south colonies. The slopes of the lines are significantly different ($p=0.00383$, $F_{1,16}=11.415$).

breeding habitat geomorphology, patterns of snow deposition and penguin population trends.

The breeding population trends analysed includes 10 years (1989-1998), and is based on colony censuses performed in accordance with standardised methods (CCAMLR 1992) during the peak egg-laying period. Five years of breeding success data (1993-1998) supplement the long-term colony censuses. At the beginning of the study in 1989, there were 23 Adélie penguin colonies ranging in size from 30 to 1400 breeding pairs. Tourist access was limited to 12 of these colonies (3310 breeding pairs), leaving 11 colonies (4625 breeding pairs) as unvisited control sites (Fig. 2).

Statistical Analyses

Statistical analyses were done using Statistica 99 (Statistica 1999) and Prism 3.02 (GraphPad 2000). Given the dichotomous nature of the data (tourist-visited vs. control-unvisited, north aspect vs. south aspect), linear discriminant function analyses were used to evaluate the predictability of group membership. Specifically, discriminant analysis was used to determine whether colony-specific habitat components (colony aspect, colony area and colony shape) could be used to discriminate between colonies undergoing high population decline (>25%) and those colonies undergoing low population decline (<25%) during 1989-1998. Discriminant analysis was also used to evaluate the ability of colony-specific breeding biology parameters (change in number of breeding pairs, percent decrease in breeding pairs per colony, percent decrease in the number of chicks produced per colony, and the number of chicks crêched/pair/colony) to discriminate between the tourist-visited and control sides of Torgersen Island. Linear regression analyses were used to assess whether breeding biology parameters supported the model results generated by the discriminant function analyses. Specifically, linear regression analyses were used to examine whether colony-specific habitat components were significant predictors of breeding population parameters (e.g., breeding population size, breeding success, nest loss and chick loss) based on the 1993-1998 breeding data. Linear regression analysis was also used to examine the relationship between snow pack persisting into late November (the peak egg-laying period for Adélie penguins) and the number of chicks crêched per colony.

RESULTS

The results of this study suggest that colony aspect and colony area are significant predictors of change in Adélie penguin populations on Torgersen Island. Rates of seasonal snow deposition and accumulation are more pronounced on Torgersen Island's south side as the hillshade model (Fig. 3) clearly demonstrates. Colonies on the south side of Torgersen Island's east-west bisecting ridge (see Fig. 3) decreased at a rate nearly two times that of colonies situated on the north side (58% vs. 32%, Fig. 4). The difference in the slopes of the regression lines was highly significant (p=0.00383, $F_{1,16}$=11.415).

Table 1. The numbers and percent of colonies that were correctly classified by the linear DFA into high colony population decrease (>25%) and low colony population decrease (<25%) categories (between 1989/90 and 1998/99). The three discriminating variables were colony aspect, colony area and colony shape (perimeter/area ratio). Colony shape did not contribute significantly to the discriminating power of this model (partial lambda = 0.812).

Group	Percent correct	Colonies classified into Low	High	Total
Low (<25%)	85.71	6	1	7
High (>25%)	100.00	0	16	16
Total	95.65	6	17	23

Fraser & Patterson (1997) speculated that egg and/or chick mortality may need to be considered within the context of colony-specific features, such as size or aspect, to better understand the underlying mechanisms driving natural variability in these populations. A 3-variable discriminant analysis of colony aspect, colony area and colony shape was highly effective in classifying high and low percentage decline colonies (Table 1). Colony aspect and colony area were the strongest predictor variables, while colony shape did not contribute substantially to the discriminatory power of the model. Only one of the 23 colonies was misclassified by the model, thus reinforcing the importance of habitat-specific features in predicting colony-scale population trends. Linear regression analyses strongly supported the discriminant model results presented in Table 1. Colony aspect, colony area and snow depth in November were identified as significant predictors of several breeding success parameters (Table 2).

To look for possible effects due to human activity, subsets of colonies were matched by size and aspect on the visited and control sides of Torgersen Island. Population trends are compared in Figs. 5 & 6. The slopes of linear regressions for north-facing colonies paired by area were not significantly different between visited and unvisited colonies (Fig. 5). However, the slopes of the linear regressions for south-facing colonies were significantly different between visited and unvisited colonies (Fig. 6). Although this may imply a tourism effect, it is worth noting that all 4 colonies representing the visited side of the island were in the areas least attended by tourists. This observation suggests that other influences may be affecting these relatively isolated, yet tourist-accessible, south-facing colonies.

Table 2. Coefficients of determination from linear regression analyses assessing the predictive ability of colony-specific habitat parameters on various reproductive parameters of Adélie penguins.

	r^2	p-value	Analysis Years
Colony aspect			
Long-Term Breeding Population Change	0.36	p<0.003	1989/90 – 1998/99
Breeding Population Decrease (percent decrease) excluding a single outlier identified by residual analysis.	0.50	p<0.0007	1993/94 – 1995/96
Chick Loss (Percent Change)	0.38	p<0.004	1994/95 – 1998/99
Colony Size (Breeding Pairs)	0.47	p<0.0006	1994/95 – 1998/99
Colony area			
Colony-specific Egg Loss at RSGs, excluding a single outlier identified by residual analysis.	0.75	p<0.0002	1993/94 – 1995/96
Snow depth			
Breeding Success (total chicks/total breeding pairs) by Maximum Snow depth in Late November excluding a single outlier identified by residual analysis.	0.78	p<0.001	1995/96

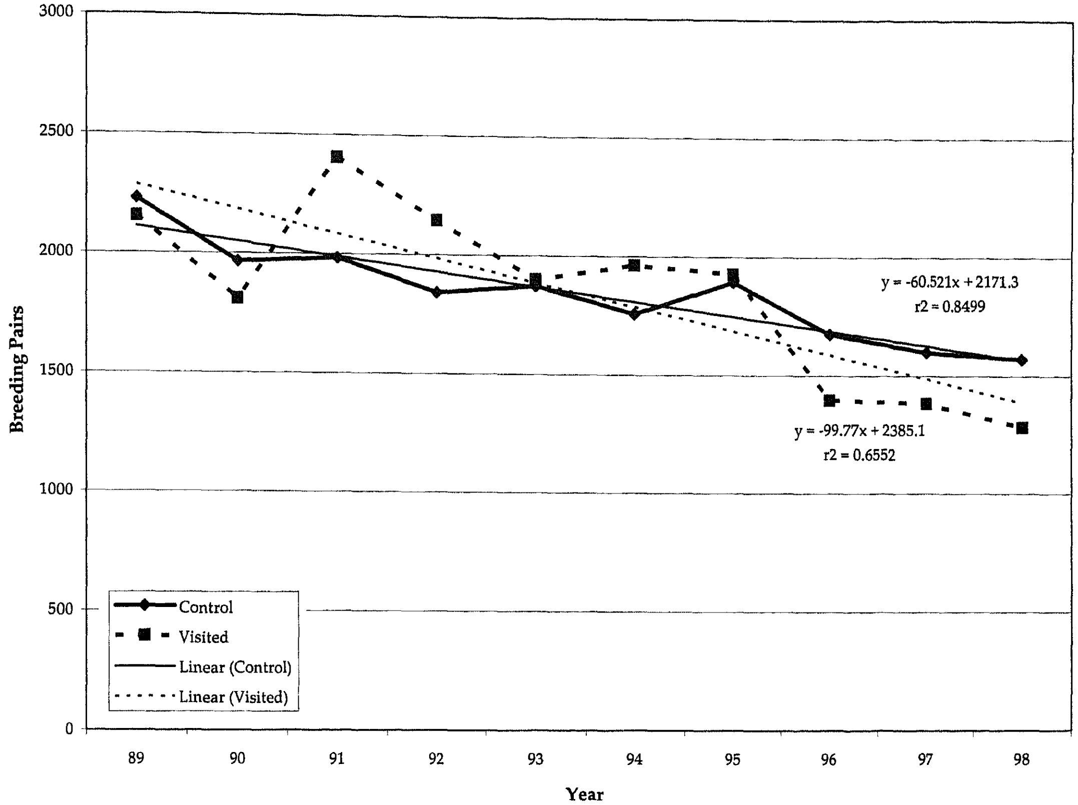

Fig. 5. Adélie Penguin Breeding Population Trends on the Control and Visited Sides of North-Facing Colonies on Torgersen Island. The trends are based on 5 pairs of colonies that were matched by size at the start of the study (1989). The slopes of the lines are not significantly different (p=0.202, $F_{1,17}$=2.094).

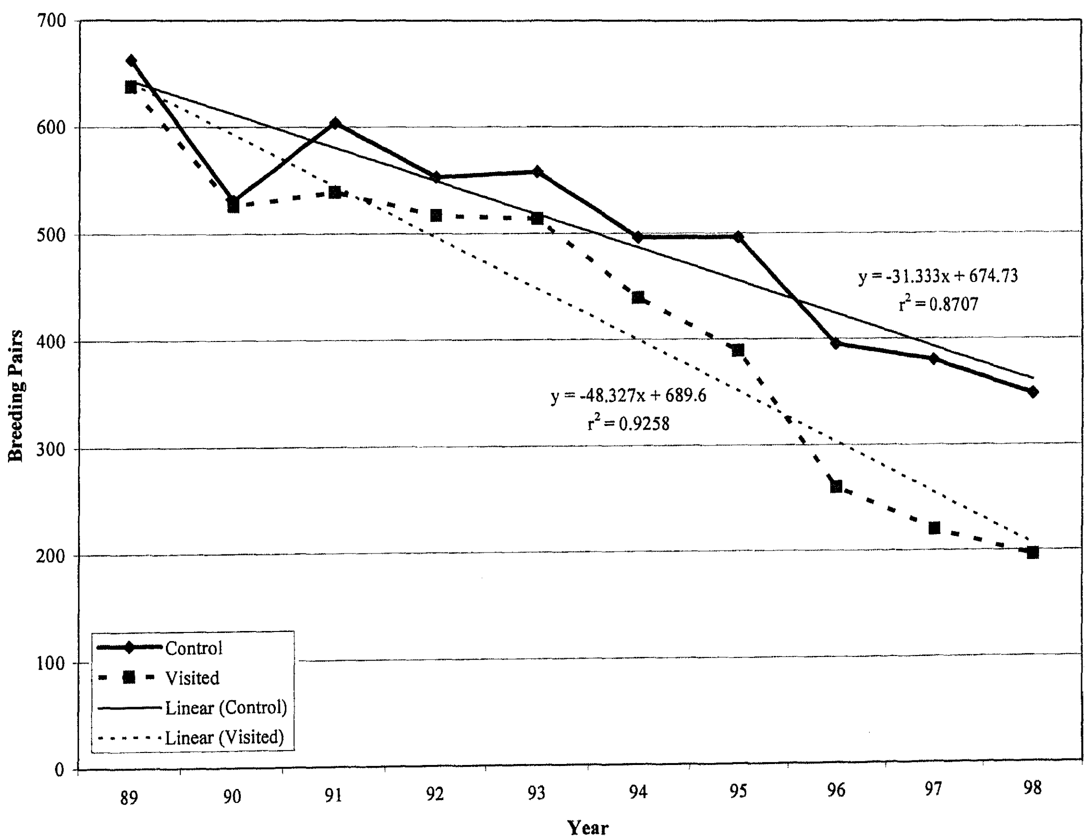

Fig. 6. Adélie penguin Breeding Population Trends on the Control and Visited Sides of South-Facing Colonies on Torgersen Island. The trends are based on 4 pairs of colonies that were matched by size at the start of the study (1989). The slopes of the lines are significantly different (p=0.0180, $F_{1,16}$=6.940).

Table 3. The numbers and percent of colonies that were correctly classified as tourist-visited or control colonies. The two discriminating variables were percent decrease in the number of breeding pairs and the number of chicks crêched/pair/colony.

Group	Percent correct	Colonies classified into		
		Visited	Control	Total
Tourist (visited)	83.33	10	2	12
Control (unvisited)	63.64	4	7	11
Total	73.91	14	9	23

A 4-variable linear discriminant analysis of change in the number of breeding pairs, percent decrease in breeding pairs per colony, percent decrease in the number of chicks produced per colony, number of chicks crêched per colony was unable to adequately discriminate between tourist-visited and control (unvisited) colonies. Six of the 23 (26%) colonies were misclassified. An examination of the relative magnitudes of the standardized discriminant function coefficients indicated that the variables percent decrease in the number of breeding pairs and the number of chicks crêched/pair/colony may have relatively greater predictive power for classifying colonies as tourist or control colonies. However, the discriminatory power of this 2-variable model did not improve. Table 3 shows the resulting classification. Two of the 12 (17%) visited-side colonies and 4 of the 11 (36%) control colonies were misclassified, suggesting that tourist activities did not impact these demographic parameters enough to discern group membership.

DISCUSSION

The Adélie penguin is the only *Pygoscelid* species with a circumpolar distribution and a breeding range that spans nearly 20 degrees in latitude (Woehler 1993). Adélie penguins thus range over an area that varies extensively in the quality and availability of breeding habitat, marine resources and exposure to other wildlife and human activity. Until recently, however, differences in Adélie penguin population trends were explained primarily by variability in the marine environment (e.g., Fraser *et al.* 1992, Smith *et al.* 1999). Evidence that these explanations could not account for the differences in trends observed in some local populations, however, led Fraser & Patterson (1997) to propose that demographic influences involved a minimum of two scales of processes. Variability in the marine environment was the most likely explanation for regional-scale trends because the processes would encompass metapopulation scales (i.e., through changes in climate, sea ice or food web processes; Whitehead *et al.* 1990, Blackburn *et al.* 1991, Fraser *et al.* 1992, Smith *et al.* 1999). Variability in nest site characteristics associated with the terrestrial breeding habitat, on the other hand, was the most likely explanation for differences in local-scale trends because the influences only encompassed specific populations (i.e., imposed through mechanisms such as the earlier described landscape effect; Fraser & Patterson 1997, Fraser *et al* in prep.). Although this marine/terrestrial model has now emerged as a more robust explanation of demographic variability in Adélie penguins (cf. Fraser & Trivelpiece 1996, Smith *et al.* 1999), aspects of this model remained untested and its potential application for detecting and interpreting the effects of human activity had not been addressed. Our results are discussed from this perspective.

This study supports the conclusion that landscape effects appear to have a greater influence on Adélie penguin breeding population trends than human presence on Torgersen Island. In this study, exposure to tourist activities cannot account for all of the observed changes in Adélie penguin populations. Stronger predictors of population change included features associated with the geomorphology of the landscape on which penguins colonies were located, and in particular possible interactions between colony aspect, colony area and snow depth (Tables 1-3; Figs. 4-6). To conclude that tourists have no impact on Adélie penguins on Torgersen Island, however, may at this point be premature. This is suggested by Fig. 6, which shows that breeding population decreases in colonies with south facing aspects were larger in the visited areas (69.3% vs. 47.5%). A possible explanation is that poor breeding habitat combined with tourist visits engenders colony-specific cumulative effects. Another explanation is that the activities of researchers may also be involved (Patterson 2001); this is the subject of current, on-going investigations.

Antarctic tourism is expected to grow substantially in the foreseeable future; hence the conclusion that there are no tourism effects on Adélie penguin demography on Torgersen Island must be placed in its proper context. This conclusion does not imply that tourists aren't having an impact, but rather that none could be detected above the natural variability in the system. National Science Foundation (NSF) management guidelines for Torgersen Island (see Patterson 2001) limit human contact with Adélie penguins during critical stages in their breeding chronology, which may afford some protection during the early breeding season. Indeed, few other tourist destinations are as carefully regulated. Given the continued popularity of Antarctic tourism, and considering the results of this and other studies, management guidelines should consider the timing of visits, as well as avoiding small or isolated colonies that may be disproportionately vulnerable to environmental or human influences (Tenaza 1971, Patterson 2001). The possibility that Adélie penguins habituate to human visitation should not be discounted, as suggested for other penguin species in the presence of human activity (see van Heezik & Seddon 1990, Cobley *et al.* 2000). For this reason, managers may suggest that visits be conducted in areas that have consistently received some level of tourism, rather than concentrating on 'expedition touring', in which the focus is to visit new colonies and retreat into areas rarely visited. Further research to evaluate the relationship between tourism and Antarctic penguins, or other wildlife populations, should take a cautious approach to the selection of a study site and to their understanding of what influences have shaped and continue to drive the populations on local and regional scales. As summarised in Fraser & Patterson (1997), an understanding of the conditions surrounding human presence is vital to discriminating between human and environmental influences.

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