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Remotely-operating camera network expands Antarctic seabird observations of key breeding parameters for ecosystem monitoring and management

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ABSTRACT

Antarctic seabirds are important indicators of impacts and change in Southern Ocean ecosystems, but their isolated and remote breeding populations are challenging and expensive to assess and monitor using traditional methods. Taking account of dependent species such as seabirds and seals is a critical aspect of the ecosystem-based management approach for the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). Our aim was to assess remotely-operating cameras as a tool for broad-scale seabird monitoring when time, budget, logistics or concerns of human impacts constrain direct monitoring programmes. Here we demonstrate how remotely-operating time-lapse cameras can be used for cost-effective, large-scale monitoring in the harsh Antarctic environment. We show that robustly designed cameras can operate over long periods and provide reliable data on key breeding parameters such as phenology and breeding success using the Adélie penguin as a case study. By establishing a network of cameras across east Antarctica, we are now able to match the scale of monitoring with the large spatial scales over which fisheries and climate change are expected to impact. This is a quantum advance for seabird monitoring that can directly complement CCAMLR's ecosystem monitoring programme to achieve conservation objectives under the Convention. The remote camera network concept is well suited for monitoring a wide range of colonial breeding species including seabirds, water birds and marine mammals.

Introduction

Although Antarctica and the Southern Ocean are amongst the most remote regions on earth, threats in these regions occur broadly through climate change and fisheries activities (Smetacek & Nicol, 2005), and potentially at local scales through human disturbance (Woehler et al., 1994; Trathan et al., 2008). Antarctic seabirds which forage at sea and breed on land are vulnerable to all of these threats. Seabirds can be used as indicator species for monitoring changes in marine ecosystems because of their dependence on marine prey (Cairns 1988; Croxall et al., 1988; Cury et al., 2011; Montevecchi 1993; Simberloff 1998) and, for Antarctic seabirds, key environmental features such as sea-ice which is subject to impacts from climate change (Croxall et al., 2002). They are also used as indicators of ecosystem change because they are easier to study while at their breeding sites compared with solely marine species (Piatt et al., 2007).

The indicator species concept is used for the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR) Ecosystem Monitoring Program (CEMP) as one element of its ecosystem-based approach to managing the Southern Ocean's marine living resources. CCAMLR was established to ensure that harvesting of living resources in the Southern Ocean is sustainable to both harvested and dependent species as well as the ecological relationships between them (Croxall & Nicol, 2004, Trathan & Agnew, 2010). At CEMP's inception in 1985, nations were encouraged to establish field sites around the Antarctic continent to monitor seabirds and seals which are largely dependent on the fishery target species Antarctic krill (*Euphausia superba*). Antarctic krill are important herbivores and a critical food source for many Southern Ocean vertebrates and invertebrates including higher-order predators (Nicol et al., 2008). CEMP was developed to detect the response of key ecosystem components to fluctuations in prey abundance and biomass as well as environmental conditions (Trathan & Agnew, 2010). This is achieved by measuring response

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parameters chosen to reflect short term responses (e.g. foraging trip duration over days or weeks) and longer term responses (e.g. breeding success over weeks or months) with standard protocols (SC-CAMLR 1997).

Over the coming years, CCAMLR has a priority to develop a feedback monitoring and management approach for managing the krill fishery to ensure that harvest levels and distribution are regulated so that the objectives set out in Article II of the CCAMLR Convention are not contravened (Constable 2011). In the context of a highly variable system superimposed upon apparent trends in both physical and biological components, ecosystem and fisheries management in the Antarctic must also be fully integrated with an understanding of the ecological consequences of climate change (Trathan & Agnew, 2010). Ideally, monitoring will be able to detect the impacts from fisheries activities quickly, and if possible, to distinguish them from responses due to environmental variability and change (Croxall et al. 1988). However, CEMP faces several challenges in achieving these objectives. The first is that the largely opportunistic location of CEMP sites is unlikely to support appropriate broad scale monitoring required to detect impacts from fisheries and to separate these from impacts that may arise from environmental forcing (Trathan & Agnew, 2010). The second is that the monitoring methods prescribed for CCAMLR (SC-CAMLR 1997) are labour intensive and subsequently areas along the Antarctic coastline have large gaps between CEMP monitoring sites. Finally, CCAMLR has reported a decline in the number of monitoring parameters and sites regularly reported to the CCAMLR Secretariat (SC-CAMLR, 2008) and this is likely to continue as financial constraints on national programmes increase. If CCAMLR is to meet its obligations under the Convention, a continuation and expansion of monitoring activities at the appropriate spatial and temporal scales for ecosystem management is required. This will almost certainly need to include alternative methods and approaches.

The concept of expanding the spatio-temporal scales of monitoring for conservation and management is consistent with shifts in ecology from studying local-scale processes towards measuring and understanding large-scale ecological processes and metapopulation dynamics across landscapes, seascapes or bio-regions (Jones 2011). This shift reflects the recognition by theoretical ecologists of the importance of dispersal and source-sink dynamics between local populations for the overall persistence of a species (Hanski 1998), and by applied ecologists and conservation managers that ecosystem drivers such as climate change, exploitation, and habitat loss are operating over increasingly large scales (Butchart et al., 2010). This shift in scale, and the need for research and management agencies to operate within tight logistic and financial constraints (Field et al., 2005), has led to increased development and application of remote observation methods for cost-effective ecological monitoring at large spatial scales (Kerr & Ostrovsky, 2003; Morisette et al., 2009). Photography is one form of remote observation that has been used for many decades in small-scale studies (Harris 1982; O'Connell et al., 2011). Ecologists and conservationists are now considering how photography can be used to monitor across large spatial scales by establishing camera networks (Ahumada et al., 2011).

We describe here the application and evaluation of a camera network for large-scale monitoring of breeding parameters of Antarctic seabirds breeding in east Antarctica. This region has few active research stations along the extensive 5000 km coastline and hence ecological monitoring studies are extremely limited. Even where research stations exist, weather and barriers to travel such as dangerous ice conditions make it difficult to access most seabird breeding sites repeatedly or at specific times of the breeding season relevant for measuring breeding parameters. To extend existing seabird monitoring efforts, we developed a remotely-operating camera that was suitable for the harsh Antarctic environment as described in Newbery and Southwell (2009). Here, we discuss the results obtained since their initial deployment and describe their use for collecting breeding parameter data that are relevant to CCAMLR and for understanding the impacts from climate change. We also highlight the potential use of cameras beyond these specific parameters and outline some of the research required to fully utilize the concept. Our motivation in developing this system was to: (1) provide a low-cost, practical means of collecting data on seabird breeding parameters at multiple sites, (2) enable frequent observations to be made with high certainty at important times during the breeding season, (3) measure seabird breeding parameters and environmental covariates that will reflect impacts from both climate change and fisheries, and (4) minimize disturbance to seabirds when collecting data.

Methods

Here we describe and assess the utility of remotely-operating cameras to expand seabird monitoring efforts in Antarctica. We focus on three aspects of their use including: (1) camera performance, (2) evaluation of the accuracy of camera-based measurement of phenology and breeding success, and (3) cost-effectiveness for monitoring over broad spatial and temporal scales. We selected the Adélie penguin (*Pygoscelis adeliae*, Fig. 1A) as an initial focal species to assess the utility of the camera network because it is the most abundant seabird breeding along the east Antarctic coastline and is an important indicator species for the CEMP in this region. The biology underlying the Adélie penguins' breeding cycle is also well known and hence comparisons with data obtained from camera images can be assessed in that context.

Time-lapse camera system

We used a time-lapse camera system specifically designed to operate over long periods with minimal maintenance in the harsh Antarctic environment. The system comprises a digital single lens reflex camera (Canon™ EOS-300D, -350D or -1000D) housed within a Pelican™ brand weather-proof case (type 1300) fitted with a transparent window, an external protective cover to prevent the window being abraded or covered by snow and dust when the camera is asleep, a programmable controller to regulate the timing and frequency of photographs, a solar panel to provide power, a surveyor's tripod (leg length 700 mm) with azimuth/elevation control, and a plastic mat to allow the tripod to be secured to the ground with rocks (Newbery & Southwell, 2009, Fig. 1B). The system is light-weight (14 kg), fits into a backpack for easy transport, and modular in design to allow easy setup by a person with no technical experience.

Evaluation

We evaluated the utility of the camera system to measure and monitor breeding phenology and breeding success parameters. Shifts in breeding phenology (the timing of breeding events) are considered to be the simplest response of a species' ecology to climate change (IPCC 2007) and may have important demographic consequences through mis-matching or de-coupling of trophic interactions and ecosystem processes (Forcada & Trathan, 2009). Important seabird phenology events include arrival at the breeding site, egg-lay, egg-hatch, chick-independence and fledging. Seabird breeding success is a key demographic parameter that can be affected by natural ecological processes such as prey availability, predation, parental provisioning and weather, and by human activities such as visitation and fisheries (Cairns 1988; Cury et al., 2011). Breeding success is measured as the number of chicks