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Original Articles

Application of a multi-disciplinary approach to reveal population structure and Southern Ocean feeding grounds of humpback whales

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ABSTRACT

Obtaining direct measurements to characterise ecosystem function can be hindered by remote or inaccessible regions. Next-generation satellite tags that inform increasingly sophisticated movement models, and the miniaturisation of animal-borne loggers, have enabled the use of animals as tools to collect habitat data in remote environments, such as the Southern Ocean. Research on the distribution, habitat use and recovery of Oceania's humpback whales (*Megaptera novaeangliae*) has been constrained by the inaccessibility to their Antarctic feeding grounds and the limitations of technology. In this multi-disciplinary study, we combine innovative analytical tools to comprehensively assess the distribution and population structure of this marine predator throughout their entire migratory range. We used genotype and photo-identification matches and conducted a genetic mixed-stock analysis to identify the breeding ground origins of humpback whales migrating past the Kermadec Islands, New Zealand. Satellite tracking data and a state-space model were then used to identify the migratory paths and behaviour of 18 whales, and to reveal their Antarctic feeding ground destinations. Additionally, we conducted progesterone assays and epigenetic aging to determine the pregnancy rate and age-profile of the population. Humpback whales passing the Kermadec Islands did not assign to a single breeding ground origin, but instead came from a range of breeding grounds spanning ~3500 km of ocean. Sampled whales ranged from calves to adults of up to 67 years of age, and a pregnancy rate of 57% was estimated from 30 adult females. The whales migrated to the Southern Ocean (straight-line distances of up to 7000 km) and spanned ~4500 km across their Antarctic feeding grounds. All fully tracked females with a dependent calf (n = 4) migrated to the Ross Sea region, while 70% of adults without calves (n = 7) travelled further east to the Amundsen and Bellingshausen Seas region. By combining multiple research and analytical tools we obtained a comprehensive understanding of this wide-ranging, remote population of whales. Our results indicate a population recovering from exploitation,

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and their feeding ground distribution serves as an indicator of the resources available in these environments. The unexpected Kermadec Islands migratory bottle-neck of whales from several breeding grounds, variable distribution patterns by life history stage and high pregnancy rates will be important in informing conservation and management planning, and for understanding how this, as well as other whale populations, might respond to emerging threats such as climate change.

1. Introduction

Using animal-borne loggers to monitor the movement and behaviour of wide-ranging predators such as marine mammals, can provide valuable information on the environmental conditions in extreme habitats such as the Southern Ocean (e.g. Aarts et al., 2008; Hindell et al., 2016). Additionally, cross-discipline collaborations can be helpful in identifying patterns in animal movements that are often important when designing conservation strategies (Hays et al., 2016). Therefore, it is increasingly important to collect a suite of data when undertaking field studies in remote sites, or when examining species that are rare, elusive or unable to be caught. Studying migratory animals across their full range poses logistical and operational challenges, particularly for studies of large animals in the complex marine environment (e.g. Heupel et al., 2015). Yet, migration is important for many marine animals, including baleen whales which undertake some of the longest documented annual movements (e.g. Robbins et al., 2011; Stevick et al., 2011), and is therefore an important research area.

The humpback whale (*Megaptera novaeangliae*) requires specific habitats for major life functions: warm waters for breeding and calving, and cold, nutrient-rich waters for feeding. Most humpback populations undertake annual migrations between low-latitude (winter) breeding grounds and high-latitude (summer) feeding grounds (Chittleborough, 1965; Clapham & Mead, 1999; Dawbin, 1966). In the Southern Hemisphere, studying humpbacks within their breeding grounds near continental mainland or islands is logistically attainable. However, within their Antarctic feeding grounds discrete populations of these whales collectively span large areas of open ocean that are largely inaccessible (Amaral et al., 2016).

Commercial whaling heavily exploited all Southern Hemisphere humpback stocks (Clapham & Ivashchenko, 2009; Ivashchenko & Clapham, 2014) and the Oceania whales, that feed in Areas V and VI around Antarctica (Fig. 1) are still estimated to be < 50% of their pre-exploitation numbers. Their recovery is considerably slower than the neighbouring east Australian population and the reasons for this remain unknown (Constantine et al., 2012; International Whaling Commission, 2015). The migratory movements of the Oceania humpback whales as they travel across open-ocean to their remote Southern Ocean feeding grounds are poorly described, and have typically involved single individual movement data. *Discovery* tag data from the 1950s–60s provided the first limited information on the movements of a few individuals, suggesting that these whales likely moved directly north to south between their breeding and feeding grounds (e.g. Chittleborough, 1959; Dawbin, 1964). Later, matches of photo-identified (Robbins et al., 2011) and genotyped individuals (Steel et al., 2018) provided alternate, non-lethal methods of investigating the migratory destinations of this population. However, like *Discovery* tags, these methods provided only endpoint locations, omitting detailed movement information between sampling and resighting locations.

The advancement of satellite telemetry has provided the opportunity to study migratory animals, such as humpback whales, continuously for several months. Telemetry has been an effective tool for

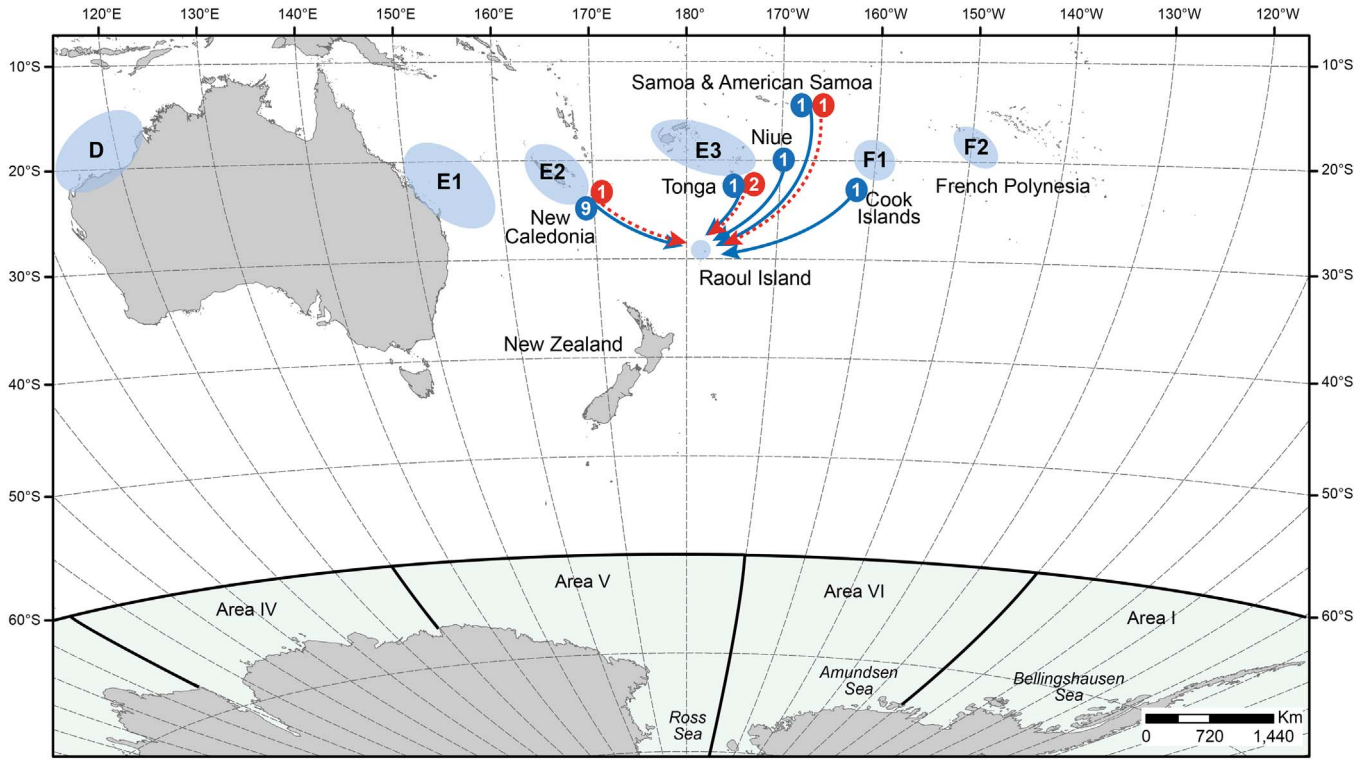

Fig. 1. Breeding (blue areas) and feeding grounds (International Whaling Commission management areas; green areas) of Southern Hemisphere humpback whales. Oceania population comprises breeding grounds E2, E3, F1 and F2. Note that only breeding grounds D-F, and feeding grounds IV, V, VI and I are shown. Arrows denote photo-identification (solid blue) and genotype matches (dashed red) in the current study between various breeding grounds of the Oceania humpback whales and the study site (Raoul Island, Kermadec Islands) in 2015.