Zoology 113 (2010) 47–56

Contents lists available at ScienceDirect

Zoology

journal homepage: www.elsevier.de/zool

Flight dynamics of Cory's shearwater foraging in a coastal environment

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ARTICLE INFO

Article history:
Received 24 March 2009
Received in revised form
5 May 2009
Accepted 26 May 2009

Keywords:
Flight dynamics
Shear soaring
Wind effect
Tail wind component
GPS loggers

ABSTRACT

Flight dynamics theories are influenced by two major topics: how birds adapt their flight to cope with heterogeneous habitats, and whether birds plan to use the wind field or simply experience it. The aim of this study was to understand the flight dynamics of free-flying Cory's shearwaters in relation to the wind characteristics on the coastal upwelling region of continental Portugal. We deployed recently miniaturised devices—global positioning system loggers to collect precise and detailed information on birds' positions and motions. Prevalent winds were blowing from the north-east and adults used those winds by adjusting their flight directions mainly towards north-west and south-west, flying with cross and tail winds, respectively, and avoiding head winds. This is confirmation that Cory's shearwaters use a shear soaring flying strategy while exploiting the environment for food: adults foraged mainly with cross winds and their ground speed was not constant during all foraging trips as it changed dynamically as a result of the ocean surface shear winds. During travelling phases, ground speed was strongly influenced by the position of the bird with regard to the wind direction, as ground speed increased significantly with increasing tail wind component (TWC) values. Adults appear to choose foraging directions to exploit ambient wind, in order to improve shear soaring efficiency (cross winding) and exploit diurnal changes in tail wind strength to maximise commuting efficiency. We report, for the first time, precise ground speed values (GPS-derived data) and computed actual flight speed values (using TWC analysis) for Cory's shearwater.

Introduction

Pelagic seabird species forage over open ocean and use a broad range of feeding methods (Ashmole, 1971), which are related to a diversity of morphologies and flight styles (Pennycuick, 1987). Although foraging styles are hypothesised to be efficient for successful foraging, they could be evolutionally modulated by a need to attract mates or escape from predators during foraging. In fact, the movement of seabird species is strongly affected by wind at various scales of analysis (Weimerskirch et al., 2000). As a result, they have to adjust their movements not only because of the hierarchical distribution of food resources but also due to changing wind conditions, in order to optimise their search pattern (Fauchald, 1999; Fritz et al., 2003). For example, roosting swifts (*Apus apus*) rely highly on wind direction and strength to minimise energy expenditure during nocturnal flight, by consistently orientating themselves to head into the wind (Backman and Alerstam, 2001).

Until recently, much of the evidence that wind strength and direction influences flying seabirds was based on global and static wind patterns usually taken from local measurements (Liechti, 2006). Now, the combination of bird tracking data with dynamic spatiotemporal wind measurements can be used to assess the dynamic relationship between wind and seabird movements in large-scale displacements, like the migration of Cory's shearwaters (Felicísimo et al., 2008).

Overall, the assessment of how wind influences seabird movements at sea is important for understanding their life history strategies and in particular how large- and small-scale environmental factors such as wind affect and modulate foraging behaviour. Seabirds can forage at huge distances from their colonies, and this is made possible in most pelagic species such as albatrosses and petrels by specific types of flight, like dynamic soaring (Wilson, 1975; Sachs, 2005). While other forms of non-powered flight, such as thermal soaring and ridge soaring, are common in terrestrial birds such as the peregrine falcon or the white stork (Ákos et al., 2008) and even oceanic species such as

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0944-2006/$ - see front matter © 2009 Elsevier GmbH. All rights reserved.
doi:10.1016/j.zool.2009.05.003

frigatebirds may utilise thermal soaring (Weimerskirch et al., 2003), dynamic soaring is a strategy by which seabirds like albatrosses can extract energy for flight from horizontally moving air, so that they can fly continuously almost without flapping.

Dynamic soaring requires wind conditions known as shear flow, which exist in a boundary layer above the ocean surface (Sachs, 2005). Pennycuick's (2002) explanation is that birds gain energy from the moving air, taking advantage of discontinuities in the wind flow and extracting from them pulses of kinetic energy. In a typical dynamic soaring cycle, birds start from the valleys of the ocean waves and (1) climb into the air, wheeling to wind. They become exposed to a head wind (that slows them down relative to the water), with increasing air speed moving over their wings. Then, (2) on an upward curve that takes them through cross winds, the birds change the flight direction to leeward (with even lower speed over the water). Thereafter, on the (3) descendent phase with predominantly tail winds, they dive back (in a fast wind-powered motion) into a wave shelter. Finally, (4) they enter a lower curve and change flight direction (flight powered by the previous phase) again to windward. By repeating these four phases, birds can save a lot of energy without having to put in much effort besides steering (see Sachs, 2005). This soaring strategy is, therefore, of particular importance to pelagic seabirds that spend almost their entire lives foraging over the ocean.

Monitoring individual seabirds' movements at sea with accuracy is now possible due to the development of miniaturised electronic devices (e.g. Wilson et al., 2007) including on-board GPS loggers (Hunerbein et al., 2000; Steiner et al., 2000; Weimerskirch et al., 2002) that store information on positioning and ground speed. There are two main measures of velocity for flying birds: the surface or ground speed (that is stored by GPS devices and is calculated in relation to the ground) and the air or flight speed (i.e. the bird's velocity relative to the air mass in which it is flying). Actual flight speed is difficult to measure in free-flying animals, so an indirect measure, the tail wind component (TWC) can be used to interpret how birds take advantage of or compensate for tail and head winds (Fransson, 1998; Garthe et al., 2007).

Several studies made use of two-dimensional data to analyse foraging strategies of flying seabirds (see review in Wilson et al., 2002), but few extended the analysis to three dimensions. One recent study by Navarro and González-Solís (2009) focused on the effect of environmental variables on the foraging strategies of Cory's shearwaters breeding on the Canary Islands. However, the fine-scale movements of birds in relation to wind characteristics were missed, perhaps because platform terminal transmitters (PTTs) are less accurate than GPS devices or because the authors used a 60 s grid rather than a continuous transmission cycle.

The main goal of this study was to test the hypothesis that Cory's shearwaters' flight strategy and daily foraging pattern is influenced by wind characteristics (strength and direction). This hypothesis was tested while individuals exploited a continental shelf area in a temperate zone and during the chick-rearing period of their reproductive cycle.

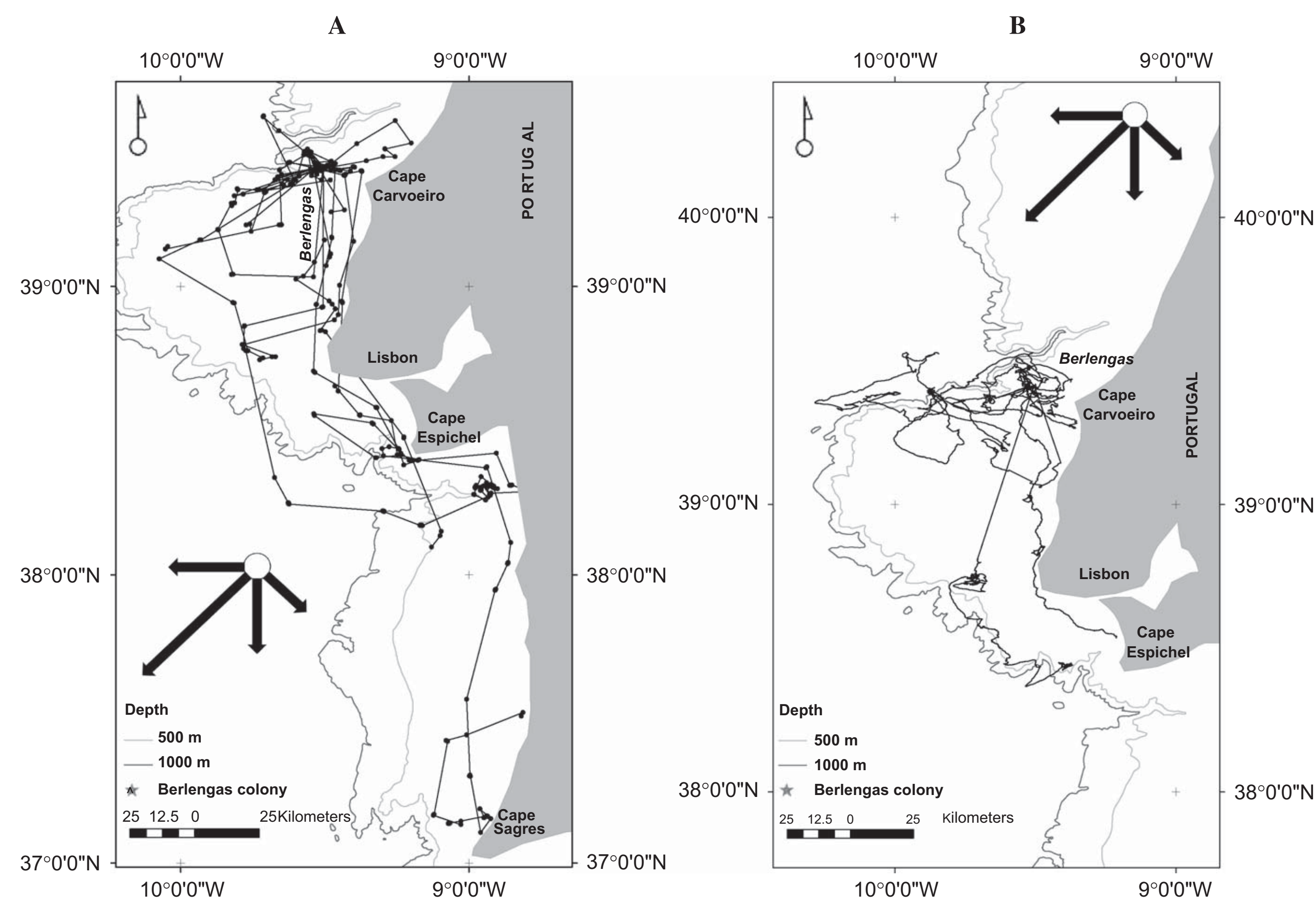

Fig. 1. Representation of all fixes, each of them connected in sequence by lines to show foraging trips. GPS loggers fixing positions (A) each 2 h or (B) each 5 s (running continuously). Devices were placed on Cory's shearwaters between 1st and 12th of September (late chick-rearing period) for a maximum continuous deployment of 7 days. Also shown: colony position (Berlengas) and depth contour lines to show the continental platform extension. Black arrows represent the strengths and blowing directions of main wind fields birds experienced during the 11 days (North–West: 9% at 11 km/h, North: 10% at 15 km/h, North–East: 71% at 20 km/h, East: 10% at 14 km/h).