Progress in Oceanography 128 (2014) 30–48

Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

Fine-scale hydrodynamics influence the spatio-temporal distribution of harbour porpoises at a coastal hotspot

A.R. Jones [a,*], P. Hosegood [b], R.B. Wynn [a], M.N. De Boer [c,d], S. Butler-Cowdry [a], C.B. Embling [e,f]

[a] National Oceanography Centre – Southampton, European Way, Southampton SO14 3ZH, UK
[b] University of Plymouth, School of Marine Science and Engineering (Faculty of Science and Technology), Reynolds Building, Drake Circus PL4 8AA, UK
[c] Wageningen IMARES, Institute for Marine Resources and Ecosystem Studies, PO Box 167, 1790 AD Den Burg, The Netherlands
[d] Marine Discovery Penzance, Shed 5, Albert Pier, Penzance Harbour, Penzance TR18 2LL, UK
[e] Centre for Ecology and Conservation, University of Exeter, Cornwall Campus, Penryn TR10 9EZ, UK
[f] Marine Institute, University of Plymouth, Marine Building, Drake Circus PL4 8AA, UK

ARTICLE INFO

Article history:
Received 23 August 2013
Received in revised form 29 June 2014
Accepted 4 August 2014
Available online 11 August 2014

ABSTRACT

The coastal Runnelstone Reef, off southwest Cornwall (UK), is characterised by complex topography and strong tidal flows and is a known high-density site for harbour porpoise (*Phocoena phocoena*); a European protected species. Using a multidisciplinary dataset including: porpoise sightings from a multi-year land-based survey, Acoustic Doppler Current Profiling (ADCP), vertical profiling of water properties and high-resolution bathymetry; we investigate how interactions between tidal flow and topography drive the fine-scale porpoise spatio-temporal distribution at the site. Porpoise sightings were distributed non-uniformly within the survey area with highest sighting density recorded in areas with steep slopes and moderate depths. Greater numbers of sightings were recorded during strong westward (ebbing) tidal flows compared to strong eastward (flooding) flows and slack water periods. ADCP and Conductivity Temperature Depth (CTD) data identified fine-scale hydrodynamic features, associated with cross-reef tidal flows in the sections of the survey area with the highest recorded densities of porpoises. We observed layered, vertically sheared flows that were susceptible to the generation of turbulence by shear instability. Additionally, the intense, oscillatory near surface currents led to hydraulically controlled flow that transitioned from subcritical to supercritical conditions; indicating that highly turbulent and energetic hydraulic jumps were generated along the eastern and western slopes of the reef. The depression and release of isopycnals in the lee of the reef during cross-reef flows revealed that the flow released lee waves during upslope currents at specific phases of the tidal cycle when the highest sighting rates were recorded. The results of this unique, fine-scale field study provide new insights into specific hydrodynamic features, produced through tidal forcing, that may be important for creating predictable foraging opportunities for porpoises at a local scale. Information on the functional mechanisms linking porpoise distribution to static and dynamic physical habitat variables is extremely valuable to the monitoring and management of the species within the context of European conservation policies and marine renewable energy infrastructure development.

Introduction

Marine megavertebrates are noted for their wide-ranging behaviour, but often concentrate within spatially constrained areas (e.g. Sims, 2003; Kai et al., 2009), referred to as 'hotspots' (Myers, 1990). The mechanism driving animal aggregations at hotspots is likely to be based on foraging decisions made in response to meso- and fine-scale environmental cues (Stephens and Krebs, 1986; Russell et al., 1992; Sims et al., 2008). By examining the distribution of a species in time and space, at a range of scales, we can improve our understanding of the species' interaction with its environment (Fauchald and Erikstad, 2002; Bertrand et al., 2008; Embling et al., 2012). This is particularly important for spatial management and conservation of threatened marine megavertebrates, such as the harbour porpoise *Phocoena phocoena*. A better understanding of the mechanisms underlying the links between porpoise distribution and physical habitat will aid in protected area site selection, as well as improving our understanding of potential anthropogenic impacts, e.g. proposed marine renewable energy infrastructure (Dolman and Simmonds, 2010; Witt et al., 2012).

* Corresponding author. Current address: The Environment Institute & School Earth and Environmental Sciences, University of Adelaide, South Australia 5005, Australia. Tel.: +61 (0)8 8313 2243.

E-mail address: alice.jones01@adelaide.edu.au (A.R. Jones).

http://dx.doi.org/10.1016/j.pocean.2014.08.002
0079-6611/© 2014 The Authors. Published by Elsevier Ltd.

Harbour porpoises are small cetaceans, which must feed regularly in order to fulfil their energetic requirements. As a result they cannot stray far from areas containing reliable prey resources (Brodie, 1995; Koopman, 1998; Santos et al., 2004; Lockyer, 2007), and the ability to react to predictable oceanographic and hydrodynamic drivers of prey availability will greatly reduce foraging costs. Broad-scale studies show that the distribution of harbour porpoises is directly influenced by the distribution of prey (e.g. Read and Westgate, 1997; Herr et al., 2009; Sveegaard, 2011) and indirectly affected by both static and dynamic environmental variables that are hypothesised to predictably influence prey distribution or foraging efficiency, such as water depth, topography, substrate, tidal flow, fronts, stratification, turbulence, and time of day (e.g. Watts and Gaskin, 1985; Johnston et al., 2005; Embling et al., 2010; Scott et al., 2010; Mikkelsen et al., 2013). However, there are no known studies investigating the fine-scale bio-physical mechanisms linking physical habitat variables to increased harbour porpoise densities, due to the rarity of the quantitative, fine-scale physical and biological data required to carry out robust investigations of these links.

Harbour porpoises have a wide coastal distribution around the UK (Reid et al., 2003; Hammond et al., 2013), making them a suitable focus species for land-based surveys. Sites around the coast of southwest England have previously been identified as hotspots for harbour porpoise (Northridge et al., 1995; Hammond, 2006; Brereton et al., 2007), with a number of studies specifically highlighting the regional importance of the Runnelstone Reef in southwest Cornwall (Leeney et al., 2008; Pikesley et al., 2012); not only in the summer months, but also throughout the winter (Evans et al., 2003; De Boer and Saulino, 2008). Using new high-resolution bathymetric data, we have been able to identify that the Runnelstone Reef site is a regionally unique bathymetric feature.

In light of the potential bio-physical links suggested by previous research, and the conservation and management policies pertaining to the species in the UK; this multidisciplinary study examines the effect of fine-scale physical habitat on harbour porpoise distribution. We investigate the drivers of porpoise distribution patterns using sightings recorded in an effort-based visual survey from a land-based watchpoint overlooking the Runnelstone Reef. The collection of co-located, high-resolution data on static and dynamic physical habitat variables, such as Acoustic Doppler Current Profiling (ADCP), water property profiles, and 1-m resolution bathymetry data, has provided a unique and timely opportunity to investigate the fine-scale spatial (~600 m resolution) and temporal (hourly resolution) distribution of harbour porpoises at a known hotspot in relation to hydrodynamics and interactions between tide and topography at the site. The main aims of the study were threefold: (1) to examine whether the spatial distribution of harbour porpoise sightings was linked to topographic features within the study area, (2) to collect high-resolution data on the physical marine environment at the study site, and (3) to investigate the spatio-temporal distribution of porpoise sightings in relation to tidal flow regime and fine-scale hydrodynamics.

Materials and methods

Study area

Survey data were collected from a land-based watchpoint on a south-facing headland (Gwennap Head) at ~30 m above mean sea level, at the southwest tip of the UK mainland (50°02′ 06.29″N 005°40′ 45.66″W). The watchpoint has an almost 180° field of view from east to west, directly overlooking the tidally dominated Runnelstone Reef (Fig. 1). The characteristics of the Runnelstone Reef create a challenging environment for data collection. Commercial fishing activities in the area restrict the strategic mooring of large arrays of acoustic monitoring equipment, and the site is wind exposed and tidally dominated, which precludes regular boat-based transect surveys at an appropriately fine scale. This results in land-based observation surveys being the most effective, and practical, method for intensive fine-scale monitoring of the distribution of porpoises at this regionally important site.

The Runnelstone Reef is a roughly horseshoe-shaped bedrock platform with an average depth of approximately 15 m out to 1.6 km, where it shallows at its southern edge, forming several upstanding pinnacles that come to within a few metres of the surface. Beyond the pinnacles, water depth drops sharply to >60 m (Fig. 1). To the east and west sides of the reef the seafloor slopes away gently and depth increases gradually. Two high-resolution multi-beam bathymetry datasets were combined to create a full bathymetric map of the survey area (Fig. 1). Inshore data (up to ~2 km offshore), at a resolution of 1 m, were collected by the Plymouth Coastal Observatory as part of the Southwest Regional Coastal Monitoring Programme (© Teignbridge District Council), and provided by the Channel Coastal Observatory. Data from further offshore (12 m resolution) were collected as part of the Maritime and Coastguard Agency (MCA) Civil Hydrography Programme (CHP) (© Crown Copyright) and are released under the Open Government Licence.

Broad-scale tidal data from Admiralty Charts show that water is driven around the headland reef by the tidal current as it enters and exits the western English Channel during the semi-diurnal tidal regime. The tidal flow through the survey area is westward (i.e. flowing out of the Channel) for the majority of the semi-diurnal cycle. Eastwards flow (i.e. into the Channel) occurs for only ~3 h per tidal cycle, between approximately 1 h before, to 2 h after high water (HW). Tidal range varies from ~1.5 m during neap tides to ~5.5 m during spring tides.

Visual surveys

Visual monitoring data were collected between 15th July and 15th October 2007–2010. The survey period was defined by the migration season of seabirds and other marine megavertebrates, which were also monitored in the multi-species survey. Observations were carried out through the full daylight period each day; this intensive constant-effort design enabled investigation of fine-scale temporal patterns in the survey data. A 2-h break was taken each day between 1200 and 1400 h, to prevent observer fatigue and avoid the period of highest glare. Observers working in pairs, with one core observer and one supporting observer. The core observers ($N = 29$ over the 4-year period) were skilled in surveying for seabirds and cetaceans, with prior field experience of identifying the target species. Selection priority was given to supporting observers who had previous marine wildlife survey experience.

Observers applied continuous search effort using 8× or 10× magnification binoculars, with naked-eye and telescope (20–30× magnification) scans of the survey area to ensure even surveillance of the near and far fields. Telescopes were also used to ensure species ID and record group size. There was rotation of survey effort between observers and regular breaks were encouraged, whilst always maintaining at least two observers ‘on watch’.

Harbour porpoise sighting records always included date, time, number of animals, movement direction and an estimate of distance and direction from the watchpoint to the point of first sighting (with subsequent sighting positions also recorded where possible). Best practice was to record direction using a compass, but on occasion a cardinal direction was used. The Runnelstone buoy was an obvious reference point, at approximately 1.6 km from the observation watchpoint, on a bearing of 170° (Fig. 1). Data