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Dredging displaces bottlenose dolphins from an urbanised foraging patch

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The exponential growth of the human population and its increasing industrial development often involve large scale modifications of the environment. In the marine context, coastal urbanisation and harbour expansion to accommodate the rising levels of shipping and offshore energy exploitation require dredging to modify the shoreline and sea floor. While the consequences of dredging on invertebrates and fish are relatively well documented, no study has robustly tested the effects on large marine vertebrates. We monitored the attendance of common bottlenose dolphins (*Tursiops truncatus*) to a recently established urbanised foraging patch, Aberdeen harbour (Scotland), and modelled the effect of dredging operations on site usage. We found that higher intensities of dredging caused the dolphins to spend less time in the harbour, despite high baseline levels of disturbance and the importance of the area as a foraging patch.

1. Introduction

The exponential growth of the human population and the increasing development of industrial activities worldwide often involve large scale modifications of the environment, with associated construction periods (McKinney, 2002; Magle et al., 2012). In the marine environment, the installation of renewable energy devices (Inger et al., 2009) together with more classic forms of offshore energy exploitation (e.g. seismic exploration, or trenching for oil and gas pipelines) (de Groot, 1982; Wardle et al., 2001) has recently raised a lot of attention. However, coastal areas have a longer history of urbanisation activities, such as land reclamation and harbour construction or enlargement (Davenport and Davenport, 2006; Jefferson et al., 2009).

The effects of construction activities on wildlife populations are largely unknown. The potential concerns range from the noise introduced into the environment (Popper et al., 2003; Weilgart, 2007) to the release of toxic compounds (Blus et al., 1993; Hedge et al., 2009) and, in general, the modification of the natural state of the habitat (Johnson et al., 2005). Animals have been observed to leave areas subject to intense construction activity (Frid and Dill, 2002; Brandt et al., 2011), and even modify their habitat use on the long-term as a result of industrial development (McLellan and Shackleton, 1988; Sawyer et al., 2006). However, the relevance of these responses for the management and conservation of populations is unknown. The disruption of animal behaviour might compromise an individual's energy balance and, consequently, its vital rates (e.g. its ability to reproduce). When repeated across most individuals in a population, this can translate into a change in the population dynamics (National Research Council, 2005; New et al., 2013). Long-term population effects are therefore likely to depend on the overall ecological landscape that individual animals experience (Gill et al., 2001; Frid and Dill, 2002; Bejder et al., 2009). The importance of the disturbed area for the population, the duration and characteristics of the disturbance source, and the trade-off between the perceived risk and the alternative habitat patches available will all contribute to determine the biological significance of any impact. For instance, we expect healthy individuals in a rich environment to avoid an area they perceive as risky. On the other hand, animals might be forced to use a disturbed patch if food is limited, the area is especially important, or their physical condition is poor (Gill et al., 2001; Frid and Dill, 2002; Beale and Monaghan, 2004b; Bejder et al., 2006).

With a total of 1481 vessels operating worldwide, the capacity of the dredging industry has increased by up to 75% since 2000 (International Association of Dredging Companies (IADC), 2011). This rapid expansion was mainly driven by the needs imposed by trade, demography, climate changes, energy, defence, and tourism (International Association of Dredging Companies (IADC), 2011).

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The construction of new harbours and the maintenance or enlargement of existing ones is topical given the increasing size and number of vessels using the oceans, and the growing needs of the offshore energy industry (Hildebrand, 2009).

Previous studies have focused on the effects of dredging on marine invertebrates and, to a lesser extent, on fish (Wilber and Clarke, 2001). The mobilisation of toxic compounds (Sturve et al., 2005; Hedge et al., 2009), the alteration of substrate composition and dynamics (Guerra-Garcia et al., 2003; Cooper et al., 2011), and the suspension of large quantities of sediments (Lewis et al., 2001) have all been documented to lead to changes in the nearby ecological communities. However, little is known about the potential effects on large marine predators. It is expected that marine predators may respond behaviourally to the elevated noise levels generated during dredging operations. Dredging noise is concentrated predominantly at low frequencies (<1 kHz), with sound pressure levels potentially greater than 180 dB re 1 μPa at 1 m (Thomsen, 2009). Detection is predicted at distances up to 6 km, depending on local conditions (Thomsen, 2009). While low-frequency noise is unlikely to mask the echolocation signals of odontocetes, it has the potential to affect cetacean communication (Weilgart, 2007) and to be perceived as a risk, thus eliciting avoidance responses (Pirotta et al., 2012). Animals' behaviour may also be affected by the increased level of shipping movements, the use of side-scan sonar and the reduced visibility associated with sediment suspension (Morris et al., 1985). Finally, predator habitat use may change as a result of the responses of prey to both noise and water turbidity (Wilber and Clarke, 2001; Popper et al., 2003). In their controlled exposure study, Richardson et al. (1990) observed bowhead whales changing their behaviour when exposed to simulated construction noise, although responses were variable. The ten year-long abandonment of Guerrero Negro Lagoon (Mexico) in the 1960s by grey whales was also linked to the shipping and dredging resulting from an evaporative salt works project (Bryant et al., 1984). In all studies, however, boat traffic and dredging activities have been confounding factors. In the absence of any conclusive evidence on the response of large predators to dredging, a precautionary approach has been generally adopted and mitigation measures put into place to minimise risks (Jefferson et al., 2009).

Here we assess the response of common bottlenose dolphins, *Tursiops truncatus*, (hereafter 'dolphins') to harbour dredging in a recently established foraging patch on the east coast of Scotland by looking at the patterns of attendance to the area over subsequent years of visual sampling. For the first time, the effect of dredging activities was tested as an added factor to normal harbour activities.

2. Materials and methods

2.1. Study system

Our study focused on the population of approximately 227 (95% highest posterior density interval: 162–384) bottlenose dolphins that range over the north-eastern coast of Scotland (Cheney et al., 2013). While in the past these dolphins tended to primarily use the inner portion of the Moray Firth (Fig. 1), a range expansion has been documented in recent years (Wilson et al., 2004), and since c. 1992 Aberdeen harbour has progressively become a stable foraging patch (Wilson et al., 2004; Stockin et al., 2006). In this area, dolphins tend to occur between the two outer piers of the harbour (Fig. 1), where they appear to feed close to the surface, in association with the tidal front created by the freshwater flow of the Dee River. The animals might use the front to aid in prey capture as they do at other locations in north-east Scotland (Mendes et al., 2002; Bailey and Thompson, 2010). Some temporal and tidal patterns of usage of the harbour have been observed in the past (Sini et al., 2005; Stockin et al., 2006), but their stability over time has yet to be demonstrated.

Aberdeen harbour is one of Europe's most active ports, due to its role as a supporting centre for the oil and gas industry in the North Sea. The harbour also sustains high levels of trade, fishing, transport and tourism, with 7784 vessel arrivals in 2011 (Aberdeen Harbour Board, 2012). 70% of this traffic is associated with the offshore oil industry and therefore involves large ships (Aberdeen Harbour Board, 2012). Most of the remaining traffic is also represented by large ships, although smaller sized boats (e.g. tugboats) are regularly present in the area. Boats transit through the channel throughout the day (e.g. http://www.aberdeen-harbour.co.uk/shipping/arrivals.jsp?type = arrivals). The importance of Aberdeen harbour is predicted to increase in the near future with the development of renewable energy on- and offshore (Aberdeen Harbour Board, 2012). This expansion will require large investments in infrastructure and consecutive intense construction operations, some of which are already being carried out. The current depth of the seabed in the area varies between less than 1 m near the shore to a maximum of 10 m in the middle of the channel.

2.2. Data collection

Land-based observations were conducted in April–June 2008, May–June 2009, and June–September 2012 from an elevated location on the shoreline (57.140°N, 2.058°W; Fig. 1). Data were collected by trained observers doing one or two three-hour shifts per day (limiting observations to good weather conditions, i.e. good visibility and Beaufort <3). Each observer only carried out one shift per day, in order to reduce the risk of fatigue. Visual scan sampling every 15 min was used to record the presence of dolphins (Altman, 1974), and covered a radius <1 km around the observation point. Given the small size of the study area (Fig. 1), it was assumed that dolphins were not missed when they were in the harbour. If dolphins were sighted, additional 5-min scans were performed. During these scans, the number of dolphins present and the number and type of boats were recorded. Moreover, the presence or absence of active dredging operations in the harbour during each scan was noted. The dredgers were only present in the channel when they were operating, and on these occasions they were visibly active. Dredging activities took place in the end of May-first half of June 2008 and 2009 to maintain the navigation channel, while in mid July-mid September 2012 the channel underwent more substantial widening and deepening as part of the planned harbour expansion.

2.3. Statistical analysis at a day level

We first focused on the day-level occurrence of the dolphins, measured as the proportion of minutes the observers detected dolphins in the harbour over the total number of minutes spent scanning the site per day. This proportion was modelled as a function of explanatory variables using a binomial Generalised Linear Model (GLM) with logit link. The explanatory variables included the proportion of scans during which dredging activity was recorded, the median, maximum and minimum number of other non-dredging related boats per scan during each day, the median and maximum size of the dolphin groups, the median tide level (obtained for Aberdeen harbour from the UK Tide Gauge Network site of the British Oceanographic Data Centre; http://www.bodc.ac.uk/data/online_delivery/ntslf/processed/) and the mode tidal state. The latter was defined as a categorical variable with four three-hour long states (low, rising, high, and falling tide) determined as 1.5 h on either side of high (high) and low (low) tide, with the remaining