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Fish behaviour in response to tidal variability and internal waves over a shelf sea bank

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ABSTRACT

The availability of fish to top mobile predators such as seabirds and fishermen and to fisheries surveys depends on their schooling behaviour. In temperate coastal ecosystems, tide is the main driver of ecosystem dynamics. To investigate the mechanisms linking fish schooling behaviour to bio-physical oceanography in a tidal ecosystem, we combined novel fine scale survey data of fish behaviour using fisheries acoustics with co-located oceanographic data from contrasting topographical locations. The schooling behaviour of pelagic fish was examined in relation to bio-physical oceanography by carrying out repeated surveys of the same locations over the daily tidal cycle at spring and neap tides over a small bank (Jones Bank) and a nearby flat region. Different fish species were found over the bank and in the flat region 14 km to the south-east, and fish schooling behaviour varied similarly. Results showed that the bank played an important role in influencing fish distribution and behaviour, with shallow pelagic schools concentrated over the bank and closer to the surface at times of high internal wave activity. Behaviour of schools identified close to the bottom was partially influenced by oceanographic variables that drove internal waves over the bank slopes, but were most strongly influenced by the spring–neap cycle. These deep schools were larger, closer to the bottom and less dense at neap tides. Identifying some the of the bio-physical variables which drive changes in fish distribution and behaviour will help quantify fish catchability and assist in the design and interpretation of better targeted surveys for top predators and prey fish species.

1. Introduction

The availability of fish to predators and to fisheries surveys is dependent on many aspects of fish behaviour (Fréon et al., 1993; Perry et al., 2000). Fish behaviour can change diurnally (Benoît and Swain, 2003; Johnsen and Godø, 2007), tidally (Michalsen et al., 1996; Embling et al., 2012), or correlated with environmental variables such as chlorophyll concentration (Robinson, 2004) and oxycline depth (Bertrand et al., 2010, 2011; Grados et al., 2012). Fishermen adapt their fishing techniques to take advantage of the behaviour of their target prey, for instance by fishing with tidal currents to maximise catches (Perry et al., 2000). Changes in fish behaviour have also been shown to have a significant effect on the foraging behaviour of other top predators such as seabirds (Embling et al., 2012). For example, sandeel schooling behaviour was shown to change with tidal currents making them more accessible to surface feeding kittiwakes, and it was hypothesised that this was topographically driven (Embling et al., 2012). Regions of steep seabed topography, such as seamounts and the shelf edge, can provide a habitat that attracts pelagic fish and other predators by producing aggregations of plankton prey species (e.g. Genin, 2004) or by supporting a suitable food resource (e.g. Sharples et al., 2009). On smaller spatial scales, internal waves over the edges of banks in shelf seas can enhance surface aggregation of prey species resulting in spatially focused foraging by top predators (Stevick et al., 2008).

Jones Bank is a relatively small (20 km × 5 km) bank within the Celtic Sea over which internal waves have been observed (Sharples et al., this issue-b), and so provides an ideal location from which to study the effect of topography and internal waves on the schooling behaviour of pelagic fish, and hence the implications for top

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predators such as fishermen and seabirds. The Celtic Sea is an important fishing ground for vessels from France, Ireland, UK, Spain and Belgium (Marchal and Horwood, 1996). It is a relatively new fishery; having only developed since the Second World War, yet despite this it has already shown changes in the trophic level and size of both surveyed and landed fish due mainly to fishing activities (Pinnegar et al., 2002; Blanchard et al., 2005). The main fish species landed have changed from being predominated by high trophic level fish such as cod and hake (e.g. *Merluccius merluccius*) to lower trophic level zooplanktivores such as horse mackerel *Trachurus trachurus*, and blue whiting *Micromesistius poutassou* (Pinnegar et al., 2002). Jones Bank within the Celtic Sea (Fig. 1) has high fishing effort in the summer months as shown from Vessel Monitoring System (VMS) data (Sharples et al., 2013a). Fisheries landings data show that the areas around Jones Bank support a fishery of mainly benthic fish such as anglerfish *Lophius* spp., and megrim *Lepidorhumbus whiffiagonis*, as well as demersal fish such as hake *M. merluccius* (Sharples et al., this issue-b; Martinez et al., this issue).

Understanding the mechanistic links between oceanography, fish distribution and changes in fish behaviour over and around a shallow bank is key to understanding top predator foraging distributions, fishery data and fish survey data. It is therefore vital for many aspects of ecosystem conservation, from the ecosystem approach to fisheries management (EAFM), to marine spatial planning including the effects of placement of renewable energy devices, to the potential effects of climate change (Inger et al., 2009; Simpson et al., 2011). The aim of this study was therefore to investigate how fish schooling behaviour contrasted between a bank site and a flat site, including any changes driven by spring–neap and semi-diurnal tidal cycles. By combining novel survey data using fisheries acoustics with co-located oceanographic information we are able to investigate important spatial and tidal contrasts in fish schooling behaviour, and suggest the role that the physics may play in determining fish behaviour.

2. Materials and methods

2.1. Data collection

The surveys were conducted between 2 and 26 July 2008 from the RRS *James Cook* in the Celtic Sea over and adjacent to Jones Bank (49.8–50.0°N, 7.9–8.1°W; Fig. 1). This paper concentrates on the repeated survey tracks carried out in two regions: over the eastern edge of Jones Bank, and in a contrasting flat region 14 km to the south-east of Jones Bank (Fig. 1). Surveys were carried out at a vessel speed of approximately 8 knots, repeatedly running circuits around a closed loop track 15 km long and 2 km wide (Fig. 1). The speed and loop circumference allowed the same location to be sampled roughly every sixth of the tidal cycle (2 h 5 min) corresponding with previous survey methods (Embling et al., 2012). The bank circuit was surveyed continuously for 25 h at both spring and neap tides: spring tides on 8 July 00:00–9 July 01:00 (C1), and neap tides on 15 July 15:00–16 July 16:00 (C3), thus each survey covering two tidal cycles and one diurnal cycle (Fig. 2). The contrasting flat circuit was continuously sampled during daylight hours only at both spring and neap tides: neap tides on 13 July 06:30–19:30 (C2), and spring tides on 20 July 04:00–19:30 (C4), so that each survey covered at least the time over one tidal cycle (Fig. 2). All times can be assumed to be Greenwich Mean Time (GMT). During each survey, synoptic monitoring of the water column and pelagic fish was carried out. Oceanographic sampling

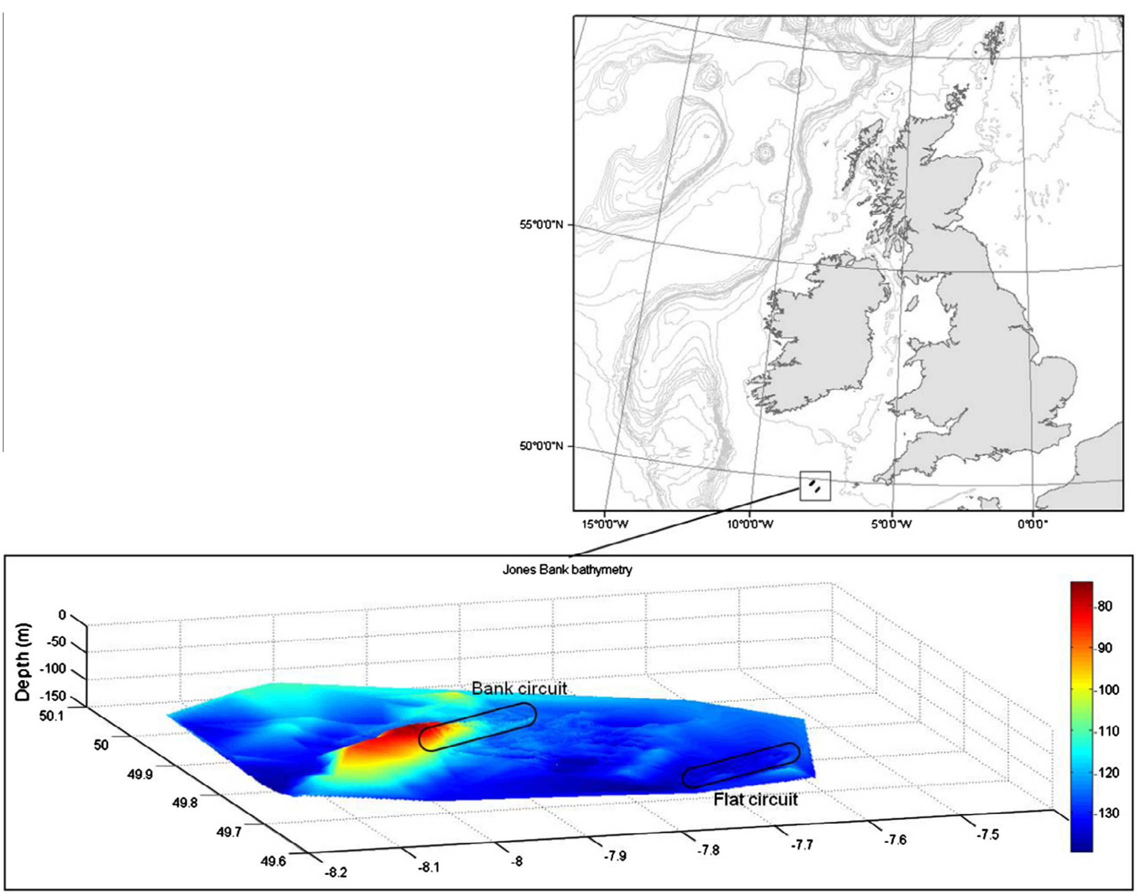

Fig. 1. Locations of the bank and flat circuits in the Celtic Sea and overlaid on the measured underlying bathymetry.