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Nuclear reprocessing-related radiocarbon (^{14}C) uptake into UK marine mammals

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ABSTRACT

To evaluate the transfer of Sellafield-derived radiocarbon (^{14}C) to top predators in the UK marine environment, ^{14}C activities were examined in stranded marine mammals. All samples of harbour porpoise (*Phocoena phocoena*) obtained from the Irish Sea showed ^{14}C enrichment above background. Mammal samples obtained from the West of Scotland, including harbour porpoise, grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) showed ^{14}C enrichment but to a lesser extent. This study demonstrates, for the first time, enriched ^{14}C is transferred through the marine food web to apex predators as a consequence of ongoing nuclear reprocessing activities at Sellafield. Total Sellafield ^{14}C discharge activity 24 months prior to stranding and, in particular, distance of animal stranding site from Sellafield are significant variables affecting individual ^{14}C activity. ^{14}C activities of West of Scotland harbour porpoises suggest they did not forage in the Irish Sea prior to stranding, indicating a high foraging fidelity.

1. Introduction

During reprocessing of nuclear materials at the Sellafield Ltd. facility (Fig. 1A), low-level radioactive waste, including ^{14}C (half-life 5730 years), is discharged to the Northeast Irish Sea, primarily as dissolved inorganic carbon (DIC; Begg et al., 1992, Cook et al., 1995). Dissolved ^{14}C is subject to solution transport and largely dispersed northwards from the Irish Sea by prevailing currents through the North Channel (Gulliver et al., 2001) and around the Scottish coastline to the North Sea (Gulliver et al., 2004). ^{14}C enters the marine food web via the efficient uptake of soluble ^{14}C in DIC during photosynthesis by primary producing organisms, i.e. phytoplankton (Cook et al., 1995; Cook et al., 1998; Cook et al., 2004; Muir et al., 2017; Tierney et al., 2017). In the UK, Sellafield discharges of ^{14}C have dominated enriched activities in the marine environment. Although Amersham International plc (now GE Healthcare), Cardiff, was an additional source causing localised enriched ^{14}C activities (Cook et al., 1998), the ^{14}C discharge activity from this site was minimal between 2000 and 2010 and negligible since 2010 (RIFE, 2016).

Since the early 1990s there have been significant changes in Sellafield ^{14}C discharges to the Irish Sea as described in detail by Muir et al. (2017). Briefly, the average discharged ^{14}C activity from 1984 to 1993 was 1.78 Tera Becquerels per year (TBq year^{-1}). An increase in the volume of waste reprocessed and a change in discharge policy in 1994, from an atmospheric route to marine discharge routes, resulted in an increase in marine ^{14}C discharges. The annual discharged activity peaked in 2003 at 16.87 TBq and remained high relative to pre-1994 releases with an average of 7.63 TBq year^{-1} until the end of 2015 (RIFE, 2016; Muir et al., 2017).

Recent studies of Sellafield ^{14}C discharges have considered the accumulation of ^{14}C within intertidal environments (Cook et al., 2004; Muir et al., 2015; Tierney et al., 2016) and the biological uptake and transfer of ^{14}C through a major part of the marine food webs of the Irish Sea and West of Scotland (Muir et al., 2017; Tierney et al., 2017). The latter studies reported enriched activities in a range of marine species occupying the lowest (phytoplankton) to middle-upper (e.g. piscivorous fish) trophic levels and described the trophic transfer of Sellafield-derived ^{14}C previously observed for intertidal organisms (Cook et al., 2004). Here we examine ^{14}C activities in marine mammals that occupy the upper trophic levels of the UK marine environment, and which are

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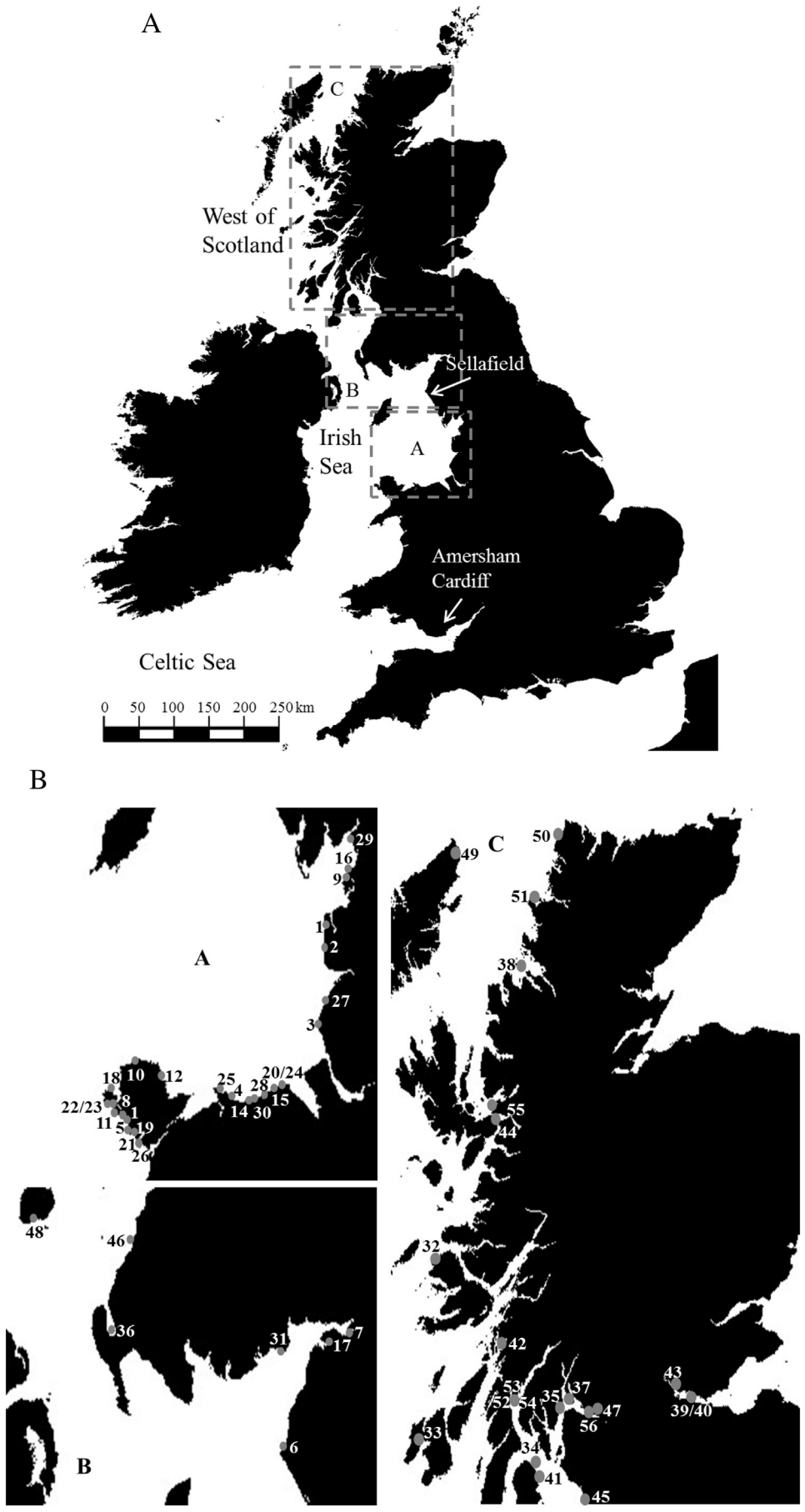

Fig. 1. A. Map of UK and Ireland indicating study areas (Irish Sea and West of Scotland) and the location of the Sellafield nuclear fuel reprocessing facility.
B. Maps of study areas and stranding locations in the southern Irish Sea (A), the transition area between the Irish Sea and West of Scotland (B) and the West of Scotland with additional sites on the Scottish east coast (C).