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BRIEF COMMUNICATION

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Serendipitous re-sighting of a basking shark *Cetorhinus maximus* reveals inter-annual connectivity between American and European coastal hotspots

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Abstract
Transatlantic stock mixing in basking sharks Cetorhinus maximus is supported by low genetic diversity in populations throughout the Atlantic Ocean. However, despite significant focus on the species' movements; >1500 individual sharks marked for recapture and >150 individuals equipped with remote tracking tags, only a single record of transatlantic movment has been previously recorded. Within this context, the seredipitous re-sighting of a female basking shark fitted with a satellite transmitter at Malin Head, Ireland 993 days later at Cape Cod, USA is noteworthy.

KEYWORDS
basking shark, conservation, genetic diversity, hotspot connectivity, mark–recapture, migration

Transatlantic stock mixing in many large marine vertebrates is supported by low genetic diversity in populations throughout the Atlantic Ocean, but direct observations of transatlantic movement are rare (Andreotti *et al*., 2016; Lieber *et al*., 2015; Skomal *et al*., 2009). Information on such broad-scale movements has, on the whole, come from commercial fisheries research (Kenchington, 2003) with studies of more esoteric species emerging over recent decades *via* satellite telemetry and mark–recapture (Hays *et al*., 2016; Kohler *et al*., 2002; Sims, 2010). Notable examples include the pan-Atlantic movements of spurdogfish *Squalus acanthias* L. 1758 (Holden, 1967), white *Carcharodon carcharias* (L. 1758) (Skomal *et al*., 2017) and porbeagle *Lamna nasus* (Bonnaterre 1788) sharks (Cameron *et al*., 2018). Genetic approaches suggest that ocean scale-mixing may also be common for other large shark species, including both blue *Prionace glauca* (L. 1758) (Veríssimo *et al*., 2017) and basking sharks *Cetorhinus maximus* (Gunnerus 1765) (Hoelzel *et al*., 2006).

The filter feeding basking shark, order Lamniformes, is the second largest fish in the world (max length > 10 m; Klimley, 2013) and is known for its seasonal surface feeding behaviour in temperate coastal waters (Sims, 2008). The mechanism by which North Atlantic Ocean basking shark stock mixing may occur was suggested by Gore *et al*. (2008) when a large (8 m+) female equipped with a pop-off archival transmitter moved from the Irish Sea to continental shelf waters off Newfoundland, Canada. Given that this was one of the first tracking studies of the species, the authors could only speculate as to how frequently such transatlantic movement might occur. Over recent decades basking shark mark– recapture studies have been conducted widely on both sides of the North Atlantic Ocean (Berrow & Johnston, 2011; Gore *et al*., 2016; Hoogenboom *et al*., 2015; Kohler *et al*., 1998;

Lieber *et al*., 2013). Collectively, these efforts have resulted in >1500 individual sharks being marked for recapture (Visual tags and Photo ID), but further evidence of transatlantic mixing has remained elusive.

Within this context, the serendipitous re-sighting of a female shark 4632 km (straight line displacement) from its original tagging site is noteworthy. This individual was fitted with a satellite transmitter (SPOT, Wildlife Computers; www.wildlifecomputer.com) housed in a unique custom-made body (Customised Animal Tracking Solutions; www.cats.is) on 24 August 2014 at Malin Head, Donegal, Ireland (55.262° N 7, 5.56° W; Figure 1a). The shark was subsequently tracked north to the Hebridean islands, Scotland where 33 days later the final ARGOS position (www.argos-system.org) was determined 5 km west of Barra, Scotland (Figure 1c,d). The re-sighting occurred after 993 days at Nauset Beach, Massachusetts, USA (41.789° N, 69.925° W) by a sub-aqua videographer on 15 June 2017 (Figure 1b). This opportunistic record links three known seasonal hotspots for the

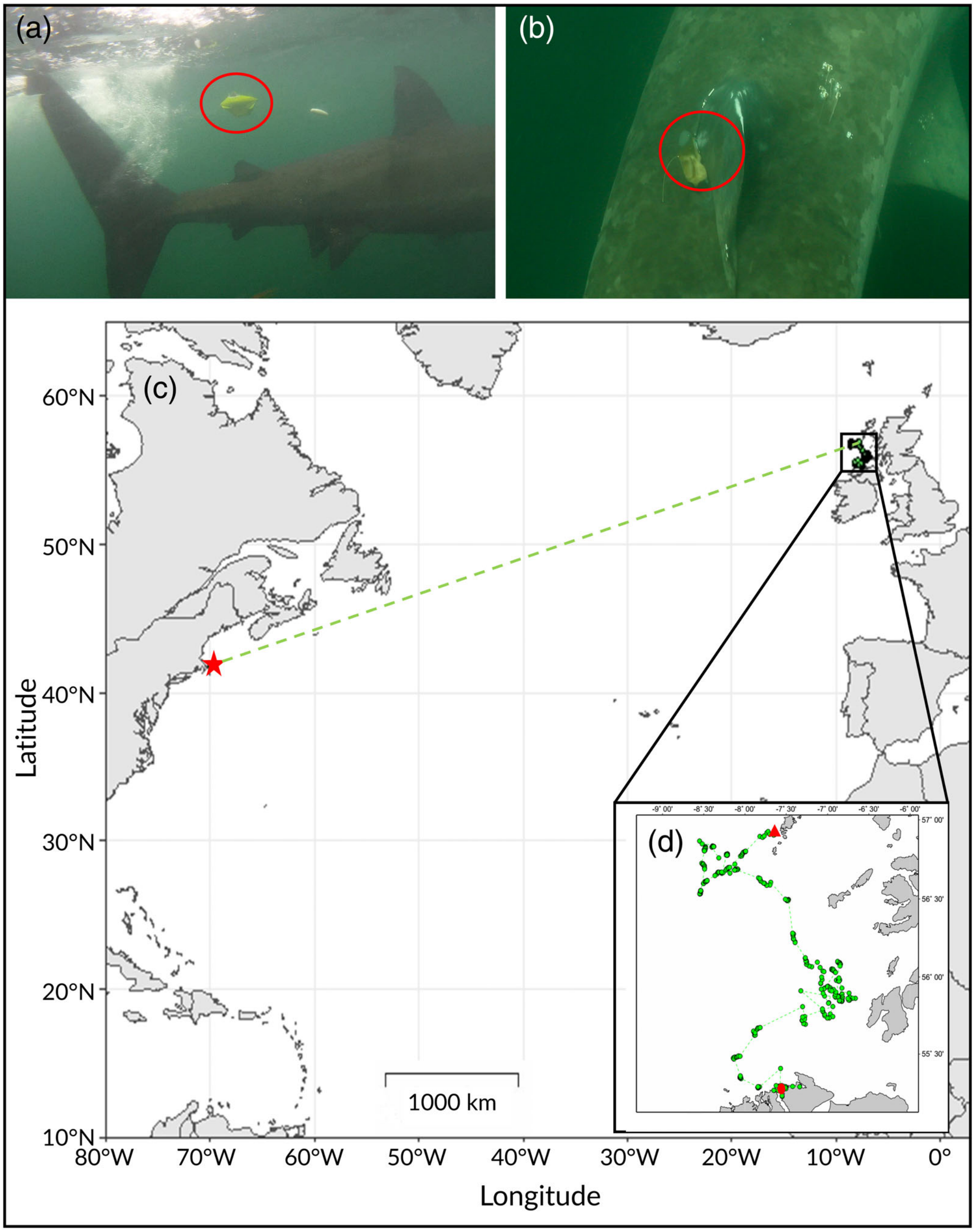

FIGURE 1 (a) Post-deployment video snapshot of the Wildlife Computers SPOT tag with CATS body (O) attached to a 5–6 m female basking shark *Cetorhinus maximus* off Malin head Donegal, Ireland. (b) A video snapshot of the damaged tag body (O) of the same tagged shark 993 days later at Nauset Beach, Massachusetts, USA. (c) A map illustrating the straight line displacement of 4632 km (- - -) from the sharks last transmitted position off western Scotland to the re-sight location at Nauset Beach, Massachusetts, USA (★). (d) The shark's northward position records (●) from its initial deployment location at Malin head, Ireland (O) to Barra, Scotland and the location of the last transmission (▲)

species (Braun *et al*., 2018; ICES, 2018; Witt *et al*., 2012) on an inter-annual scale and constitutes the first evidence of movement between European and US waters, expanding on the pioneering study of Gore *et al*. (2008).

The drivers for such long-distance movements in basking shark are likely to be diverse (Doherty *et al*., 2017a; Sims *et al*., 2003; Skomal *et al*., 2009). From previous research, a broader picture of basking shark's short to medium-term movements in response to the dynamic distribution of prey across the ocean landscape has emerged, including residence in seasonal hotspots and latitudinal migration on both sides of the North Atlantic Ocean (Braun *et al*., 2018; Doherty *et al*., 2017b; Southall *et al*., 2005; Stephan *et al*., 2011). As large-bodied planktivores, basking shark are typically associated with hydrodynamic features that contain or aggregate high densities of crustacean zooplankton (Sims, 2008). This foraging pattern often manifests itself as latitudinal movements between heterogeneous aggregations of prey over seasonal scales (Roshier *et al*., 2008); compounded in turn by reproductive and physiological needs; *e.g*., social behaviour (Gore *et al*., 2018; Sims *et al*., 2000) or thermal ecology (Braun *et al*., 2018; Carrier *et al*., 2010; Priede & Miller, 2009). However, the timing of the tag deployment in Ireland (August 2014) and re-sighting in the US (June 2017) illustrates that association with summer (April–September) hotspots in the North Atlantic Ocean might be more nuanced than previously thought. Certainly, individual sharks do return on an inter-annual basis to the same coastal hotspot (Doherty *et al*., 2017b; Gore *et al*., 2018) but this re-sighting event shows that inter-annual fidelity to a single summer hotspot is not obligate or necessarily exhibited in all individuals.

At present, transatlantic mixing in the species appears far from common but is obviously sufficient to ensure genetic population diversity remains low (Hoelzel *et al*., 2006; Noble *et al*., 2006). Given the tractable nature of basking shark for tracking studies, our understanding of their seasonal movements has gone hand in hand with advances in biotelemetry (Braun *et al*., 2018; Curtis *et al*., 2014; Doherty *et al*., 2017a; Gore *et al*., 2008; Miller *et al*., 2015; Priede, 1984; Sims *et al*., 2003; Skomal *et al*., 2009). However, the recording of patterns in individual sharks' movements on an inter-annual scale is restricted to some extent by current technology; *i.e*., battery life and biofouling of transmitters (Doherty *et al*., 2017a; Hays *et al*., 2007). Looking forward, as the longevity of satellite transmitter deployments continue to increase, we may begin to record ocean-scale movements more frequently (Costa *et al*., 2012).

When we consider that the IUCN classifies the basking shark as Endangered in the north-east Atlantic Ocean but Vulnerable in the north-western Atlantic Ocean (Fowler, 2009), the recording of this trans-Atlantic movement advances our understanding of the extent of the species multi-annual range within the North Atlantic Ocean. Furthermore, the confirmation of inter-annual trans-Atlantic connectivity between three hotspots (Ireland, UK, USA) lends support to Southall *et al*. (2006) in their call for deeper international collaboration. Specifically, the OSPAR (2015) and ICES (2018) working groups have a duty to be cognisant of the extensive range at which individual sharks operate within the Atlantic basin. It follows that there exists a pressing requirement for multi annual individual level movement data in order to observe these rarer movements that can provide great insight into population level dynamics. Moreover, consideration should be given to measures that promote the collective responsibility for the species held by all states that manage territorial waters and exclusive economic zones through which the sharks pass and or inhabit on a regular basis (Dulvy *et al*., 2008). In conclusion, an Atlantic Ocean-wide collaborative approach is required to ensure the conservation of the Atlantic oceans second largest fish species, a creature that carries no passport and recognises no national boundaries.

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ETHICAL STATEMENT

The care and use of experimental animals complied with Department of Agriculture, Food and Marine, Ireland animal welfare laws, guidelines and policies as well as the ethical research requirements approved by The National Parks and Wildlife Service, Department of Arts, Culture and Gaeltacht, Ireland. This study entailed the deployment of a Wildlife Computers SPOT tag using the standard wildlife computers titanium anchor and tether attachment method. No fish were collected as part of faunal surveys; No fish were killed during or at the end of the experiment; no surgical procedures were performed; experimental conditions did not severely distress any fishes involved in the study; No procedure in this study caused lasting harm to sentient fish and no procedure involved sentient, un-anaesthetised animals that were subjected to chemical agents that induce neuromuscular blockade.

AUTHOR CONTRIBUTIONS

E.J. and J.H. conceived and designed the Shark Spotting study from which this record arose, E.J. and P.M. undertook the fieldwork and Eric Savetsky videoed the re-sighting; all authors contributed to the writing of the manuscript.

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