Tracking Atlantic bluefin tuna (*Thunnus thynnus*) from Jersey waters

Photo (top): Underwater footage of Atlantic Bluefin tuna captured in Channel Island waters. **Photo credit**: Matthew Stockreiter, Wild Islands
Photo (bottom): The University of Exeter and Jersey Government bluefin tuna tagging team on the Anna III. **Photo credit**: John Ovenden.

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INTRODUCTION

Atlantic bluefin tuna (ABT, *Thunnus thynnus*) are a large (ca. 680 kg) scombrid fish distributed widely throughout the North Atlantic. Their population is comprised of a large eastern- and much smaller western-Atlantic sub-population. They are of commercial interest due to a high price for their meat, and by sport anglers for catch and release. Despite historic overfishing, the eastern ABT population is thought to have increased by as much as 22% in recent years (IUCN, 2021). Considering this, the eastern sub-population was recently down listed from endangered to least concern by the World Conservation Union (in September 2021, IUCN, 2021). They have also recently returned to waters off the UK and Ireland, having been common in the 1940s, and supporting a recreational fishery (Horton *et al.*, 2021).

Thunnus UK (https://www.thunnusuk.org/) is a collaborative research project between The University of Exeter, The Centre for Environment, Fisheries and Aquaculture Science (Cefas) and the Tuna Research and Conservation Centre of Stanford University, USA. Since 2018, Thunnus UK has deployed more than 120 state-of-the-art tracking tags on ABT off the United Kingdom to create a baseline understanding of their ecology. Research by Thunnus UK has revealed that ABT tracked from southwest England travelled extensively throughout the Channel, and in some cases visited Jersey territorial waters. ABT have been increasingly reported off the Channel Islands since 2016, although at present there is no baseline understanding of their local movements and life history. Any future exploitation or other use of ABT in the Channel Islands should ideally be informed by data on ABT spatio-temporal abundance and distribution in the Channel islands, and a scientific programme to gather such information would therefore be beneficial.

To provide these baseline data, The University of Exeter, UK collaborated with the Government of Jersey to deploy tracking tags in 2021 and 2022.

METHODS

ABT were caught using artificial lures (squid spreader bars with single stingers), trolled on the surface in the proximity of surface feeding shoals of ABT (or where ABT had been recently sighted). Spreader bars were used as the most refined method to catch ABT. Typically, the spreader bar exerts drag on the ABT after they take the hook, limiting how fast they can swim and how far they can "run", often leading to quicker capture times. Spreader bars also allow for stronger line to be used, and to avoid the use of live bait, which is not ethically permissible at the University of Exeter.

ABT were measured (half girth and curved fork length – CFL), sampled (fin clip and muscle biopsy) and instrumented with a Wildlife Computers MiniPAT tag (348-F; hereafter referred to as "tags"; https://wildlifecomputers.com/our-tags/pop-up-satellite-tags-fish/minipat/; n=14, **Table 1**), which were directly attached to ABT using intra-muscular titanium anchors. Tags record pressure (which can be converted to depth), temperature and light levels every 5 seconds. Depth data indicate diving behaviour, temperature data describe the thermal structure of the water column (and can be useful, for example, for confirming that a fish enters the Mediterranean Sea), and light levels at dawn and dusk are used to reconstruct the daily movements of the fish for the entire deployment period using Light Based Geolocation (Pedersen *et al.*, 2011). Tags archive these data in their memory until the end of the tracking period.

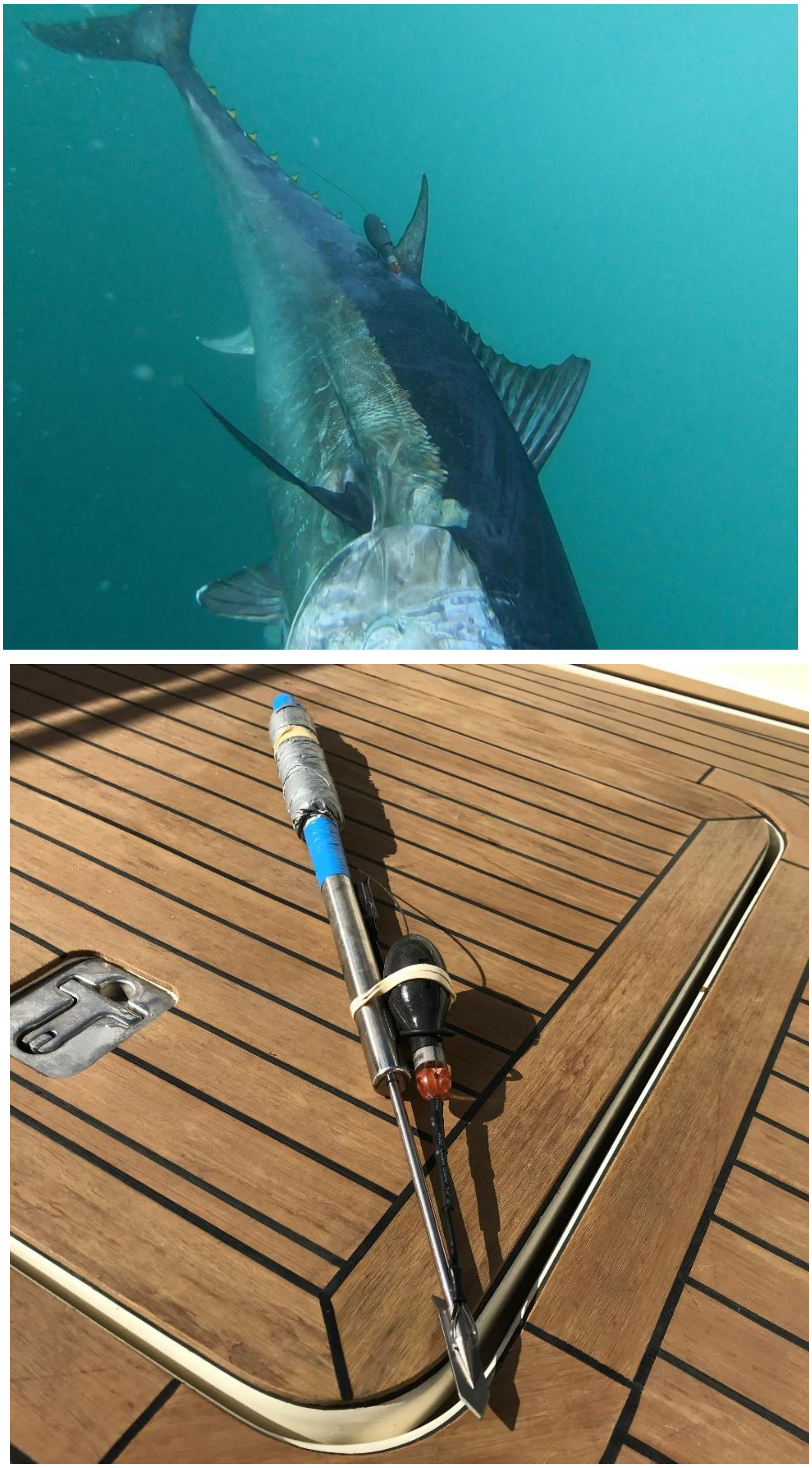

Figure 1. An Atlantic bluefin tuna carrying a MiniPAT tracking tag (grey bulbous shaped device) sitting to the right of the second dorsal fin and a MiniPAT attached to the tagging pole on the deck of a vessel before deployment **Photo credit**: Lucy Hawkes, The University of Exeter.

At a programmed date, typically 1 or 2 years following deployment, the tags detach themselves from the fish using a timed electronic-galvanic release. After detachment, tags float to the sea surface and transmit summary information from the data archive over a period of 10 to 14 days via the Argos satellite system (https://www.argos-system.org). Movements of fish are then reconstructed from data using Wildlife Computers proprietary software, "GPE3" (assuming a maximum movement of speed 2.5 m per second). Although data are transmitted by tags, the entire archive of data is only accessible if a tag is physically recovered. A subset of the fish were also tagged with Thelma Biotel HP-16 acoustic tags (n=7 acoustic tags, 64K protocol). After tagging, all fish were returned to the water tail-first and finally released after an in-water revival and monitoring period of up to 5 minutes (**Figure 1**).

University of Exeter staff provided training in ABT fishing and handling techniques to Government of Jersey staff and crew from the Anna III over 10 fishing days in 2021 and 5 fishing days in 2022. Over the course of sampling, refinements and repairs were made to reel spools, drags, outriggers and terminal tackle as necessary.

RESULTS

Fishing was conducted over 10 days in 2021 and 5 days in 2022 between west and northwest Jersey, and southwest Guernsey, with limited effort further west of Guernsey in November (**Figure 2**). During scientific fishing operations, 1,040 nautical miles of search effort were undertaken over 127 hours of fishing (**Table 2**). ABT were sighted on 12 of 15 days (80% of days) with a total of 402 surface sightings recorded (**Figure 2**). Overall, 22 ABT were hooked and 14 of those were tagged (hook-up to tag ratio of 0.6 tags deployed per hookup). Tagged ABT ranged in size from 153-212 cm (mean ± 1 S.D.: 165 ± 18 cm), and were likely between 4 and 8 years old (based on ICCAT size to age relationship; Rodriguez-Marin et al., 2016). In the event that a MiniPAT tag recorded a constant depth (± 2.5 m) for three days post-deployment, the tag software would assume mortality of the study animal, and a tag release sequence would be initiated. This condition was not met for any ABT instrumented with MiniPATs indicating that all released fish survived the procedure.

Tagging data

Movements

At the time of reporting (Feb 2023) five MiniPATs (deployed in 2021 for 1 year) have detached, while a further two MiniPATs deployed in 2021 on 2-year schedules have yet to release and transmit (due Sept. 2023). In 2022, four MiniPATs with 1 year schedules were deployed, and three MiniPATs were deployed on 2-year schedules. These will be reported on at future date once data are received (**Table 1**).

Of the five MiniPATs above, two detached prematurely due to a hardware issue (termed "pin breaks"), one on 23rd of December 2021 (and the tag was recovered and its data downloaded) and another on the 3rd of February 2022. These tags were subsequently replaced under warranty by Wildlife Computers and replacements deployed in 2022. The other three tags deployed in 2021 reported on the 11th of September 2022 (the programmed date of detachment), two from waters west of Jersey (and the tags subsequently recovered), and the third (**21P0466; Table 1**) from an embayment in the Aegean Sea off Çeşme, Turkey – a known tuna ranching area (**Figure 3 Inset**). This tag failed to transmit a dataset suitable for track reconstruction (likely because the tag was kept indoors to prevent transmission). Excluding this tag, the other four tags (two partial and two complete deployments) remained attached to ABT for 274 ± 131 days (mean ± 1 S.D.) and transmitted sufficient data for 1,001 cumulative days of location estimates to be generated.

After they were released ABT (n=4; CFL = 154 to 179, mean ± 1 S. D. = 160 ± 13 cm) remained in the Channel ecoregion for at least 54 days before dispersing to the Atlantic, with one tag reporting off Le Havre, France after 111 days (i.e. it did not leave at all during this time). After first leaving the Channel, one fish spent a further 125 days between the Irish and Celtic Seas and the Channel, before finally dispersing to the Bay of Biscay on the 3rd of March 2022 (**Figures 3, 4 and 5**). ABT dispersed as far as 947 km from the Channel Islands (cumulative along-track straight-line distance, **Figures 3 and 4**), but they all remained in the eastern Atlantic for the whole tracking period (i.e. remained east of the 45°W meridian). Two tags provided data over a whole tracking year (21P0467 and 21P0341; **Table 1**), which revealed that the Bay of Biscay was occupied for the longest period. These two tags also showed that fish maintained inter-annual fidelity to the Channel, with tags eventually releasing just 43 and 75 km from their original respective deployment locations (**Figures 4 and 5**). For these two fish, the total distances travelled (estimated along-track straight line distances) were 8,271 and 10,533 km. In total, all five tags showed that ABT were seasonal visitors to the waters of Jersey, and spent much of the year outside of Jersey waters, though more data from the tags yet to detach will confirm this further (**Figure 6**).

Diving behaviour

The four tags that transmitted data revealed that ABT spent most of their time in the top of the water column - between 0 and 5 m (grand mean ± 1 S.D. = 36 ± 22% of their time), and between 11 and 50 m depth (grand mean ± 1 S.D. = 36 ± 20% of their time; **Figure 7**). On occasion though ABT dived much deeper, to a maximum depth of 1,112 m (range = 156 to 1,112 m), and on 35 days (3% of tracking days) ABT dived in excess of 500 m depth. Diving behaviour varied both between region and time of day, with shallower maximum daily dives in the Channel (70 ± 23 m) and the Celtic Sea (100 ± 27 m) and deeper maximum daily dives in the Bay of Biscay (181 ± 151 m) North Atlantic Ocean (407 ± 179 m). ABT spent more time at the surface during the night (grand mean ± 1 S.D. between 0 and 10 m – night = 62 ± 10%; day = 47 ± 15%) and spent more time at depth during the day in all regions.

Table 1. Summary statistics for electronic tag deployments off Jersey during 2021 and 2022.
Light grey shading denotes tags that have popped-up, with darker shaded rows and * also indicating tags that were subsequently recovered.

	MiniPAT	Acoustic		Deployment					Pop-up				
Deployment Type	**Serial number**	**Serial number**	**ICCAT Floy**	**Date**	**Lat, WGS84**	**Long, WGS84**	**CFL | Half Girth, cm**	**Estimated weight, lbs (age, years)**	**Program Date**	**Actual date (days at large)**	**Lat, WGS84**	**Long, WGS84**	**Data days (%)**
1Y MiniPAT	21P0469	-	077675	04-Sep-21	49.10	-2.44	154 | 49	113 (5)	11-Sep-22	03-Feb-22 (152)	44.71	-2.21	101 (66)
***1Y MiniPAT**	21P0468	-	077669	04-Sep-21	49.08	-2.34	153 | 49	112 (5)	11-Sep-22	23-Dec-21 (110)	50.08	-0.57	110 (100)
***1Y MiniPAT**	21P0467	-	077650	05-Sep-21	49.07	-2.40	179 | 57	117 (6)	11-Sep-22	11-Sep-22 (371)	49.27	3.30	371 (100)
1Y MiniPAT	21P0466	-	077652	06-Sep-21	49.09	-2.37	212 | 65	273 (8)	11-Sep-22	11-Sep-22 (370)	38.35	26.40	3 (<1)
***1Y MiniPAT**	21P0341	-	077676	07-Sep-21	49.05	-2.33	154 | 52	127 (5)	11-Sep-22	11-Sep-22 (368)	48.99	2.77	368 (100)
5Y Acoustic & 2Y MiniPAT	20P1145	2127 2768	-	08-Sep-21	49.32	-2.34	179 | 56	171 (6)	25-Sep-23	-	-	-	-
5Y Acoustic & 2Y MiniPAT	20P1104	2127 2767	-	09-Sep-21	49.33	-2.39	177 | 55	163 (6)	25-Sep-23	-	-	-	-
1Y MiniPAT	21P1997	-	084096	04-Oct-22	49.24	-2.35	168 | 62	197 (5)	11-Sep-23	-	-	-	-
5Y Acoustic & 1Y MiniPAT	21P0343	2230 6784	-	04-Oct-22	49.25	-2.36	164 | 57	163 (5)	08-Sep-24	-	-	-	-
5Y Acoustic & 2Y MiniPAT	21P0354	2230 6783	-	04-Oct-22	49.26	-2.36	141 | 48	99 (4)	11-Sep-23	-	-	-	-
5Y Acoustic & 2Y MiniPAT	21P0350	2230 6785	-	07-Oct-22	49.07	-2.39	152 | 51	121 (5)	08-Sep-24	-	-	-	-
5Y Acoustic & 1Y MiniPAT	21P0355	2230 6782	-	07-Oct-22	49.05	-2.36	153 | 52	126 (5)	11-Sep-23	-	-	-	-
5Y Acoustic & 2Y MiniPAT	21P2252	2230 6772	-	08-Oct-22	49.06	-2.43	153 | 51	121 (5)	08-Sep-24	-	-	-	-
5Y Acoustic & 1Y MiniPAT	21P0365	-	077637	08-Oct-22	49.10	-2.51	164 | 55	151 (5)	11-Sep-23	-	-	-	-
Total / Mean	**14**	**7**	**7**				**165 | 54**	**151 (5)**					

Table 2. Survey effort during scientific fishing operations off Jersey during 2021 and 2022.

Date	Start	End	Fishing effort (hh:mm)	Distance covered (nmi)	Area	Sightings	Hookups	Tagged
26-Jul-21	07:00	18:30	10:00	80	SW Guernsey	0	0	0
27-Jul-21	06:30	14:30	06:00	60	West of Jersey	0	0	0
04-Sep-21	08:00	17:45	08:00	60	SW Jersey	100	3	2
05-Sep-21	07:15	16:15	08:00	60	SW Jersey	0 (foggy)	2	1
06-Sep-21	08:30	18:30	09:00	60	SW Jersey	19	1	1
07-Sep-21	08:30	19:30	10:00	60	SW Jersey	20	2	1
08-Sep-21	08:30	17:00	07:00	60	NW Jersey	11	3	1
09-Sep-21	08:30	19:30	10:00	70	NW Jersey	11	2	1
08-Nov-21	06:45	18:30	04:00	80	SW Guernsey	18	1	0
09-Nov-21	06:30	17:00	09:00	80	SW Guernsey	9	0	0
03-Oct-22	08:20	17:40	08:30	80	SW Jersey	16	0	0
04-Oct-22	08:40	18:40	09:00	80	W Jersey	25	3	3
06-Oct-22	07:00	17:30	10:30	80	SW Jersey	57	0	0
07-Oct-22	08:30	16:20	07:00	50	SW Jersey	32	2	2
08-Oct-22	07:10	18:50	10:30	80	SW Jersey	84	3	2
		Totals	**127 h**	**1,040 nmi**		**402**	**22**	**14**

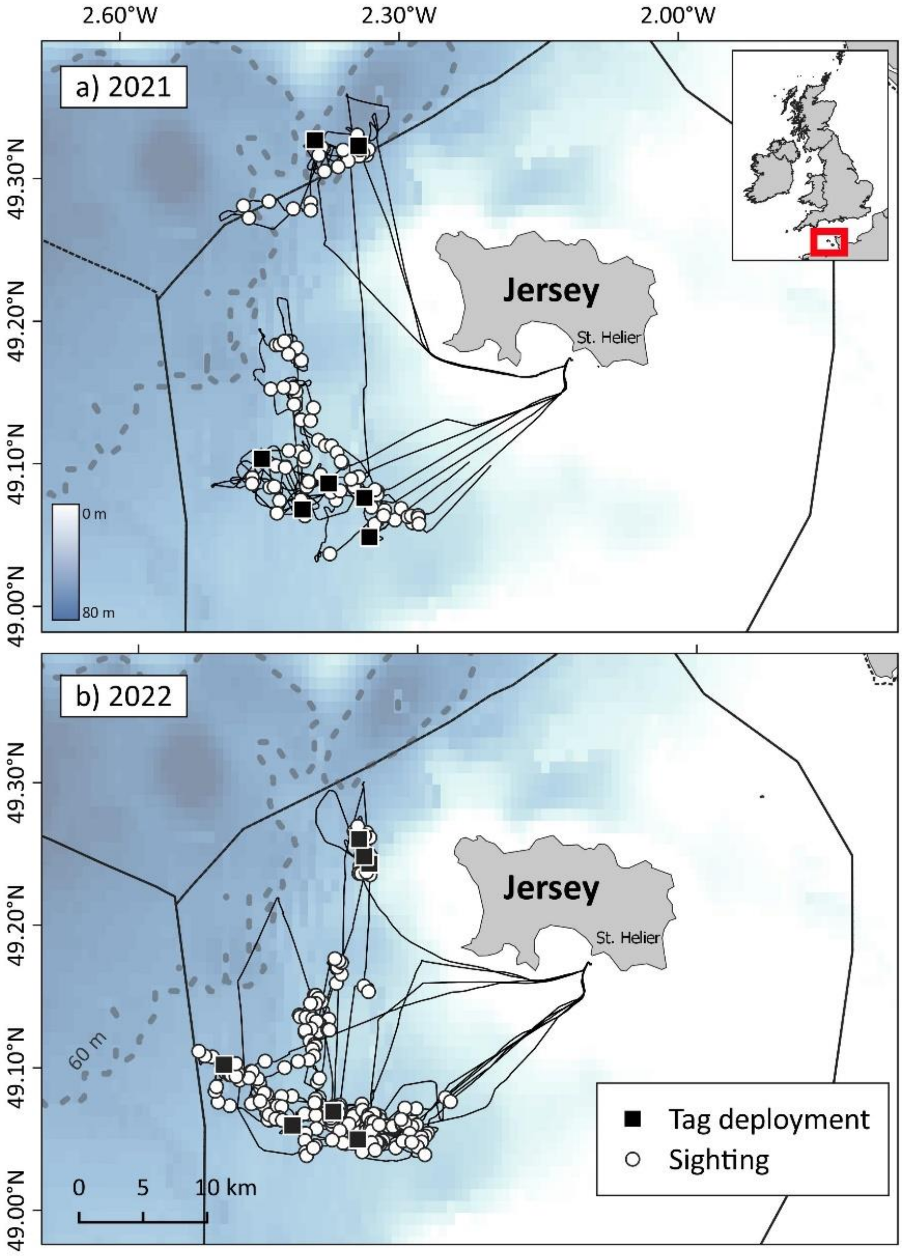

Figure 2. Vessel tracks (solid line), sightings of ABT (white circles) and tag deployments (black squares) off Jersey in 2021 and 2022. Exclusive economic zones are overlaid in bold solid black lines.

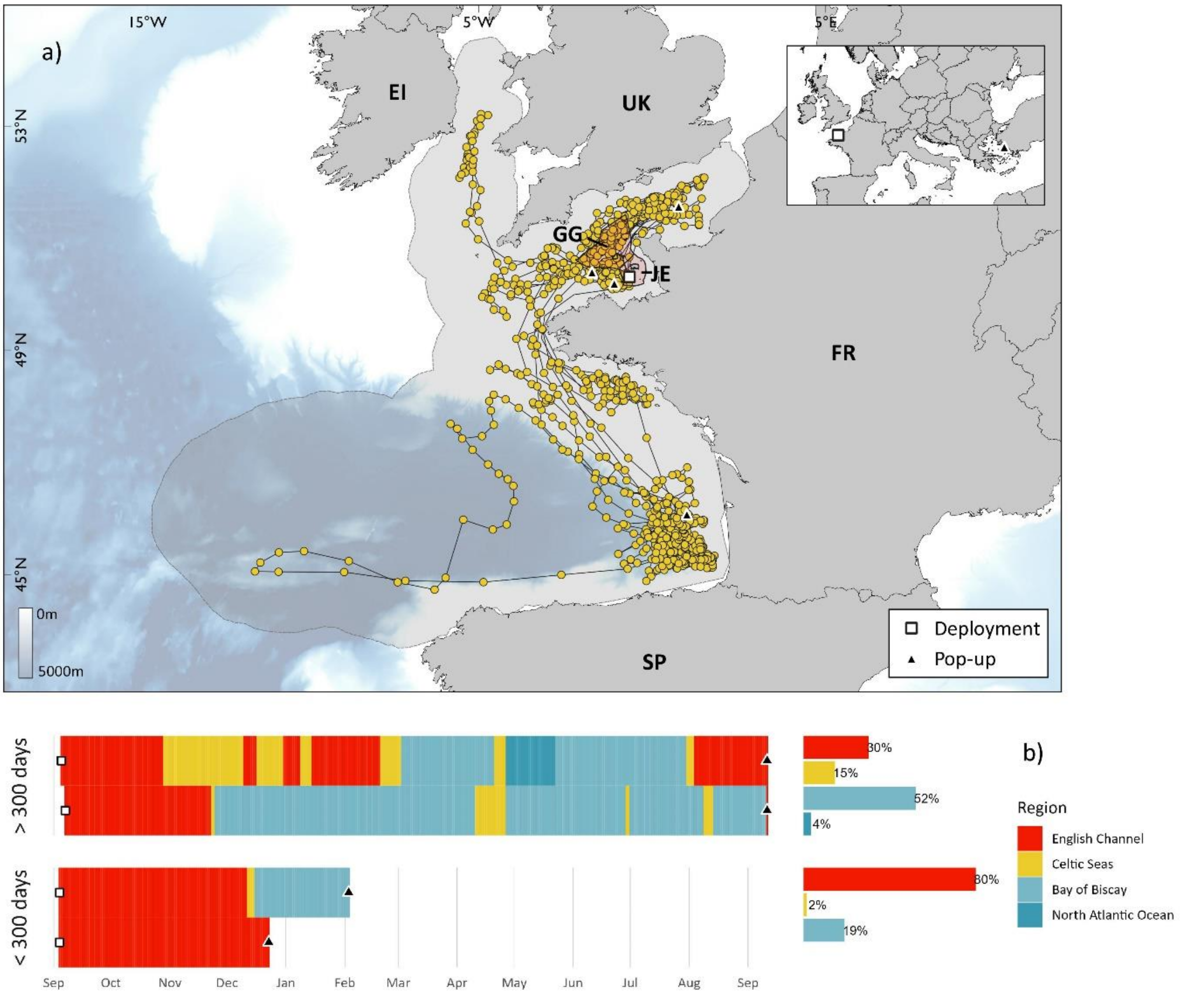

Figure 3. Dispersal behaviour of ABT tracked from Jersey. a) Map showing modelled daily locations for four ABT. Grey shaded area denotes the 99% probability surface for all tags combined. Pink shaded polygon denotes the exclusive economic zone of Jersey and Guernsey. Inset map shows the tagging and pop-up locations of one tag that transmitted from Turkish waters, but which did not transmit enough data for track reconstruction. b) Gantt chart showing movements of individual ABT (one fish per row) over time summarised by IHO region that the fish occupied. Inset barplot shows the grand mean percent of time in each IHO region.

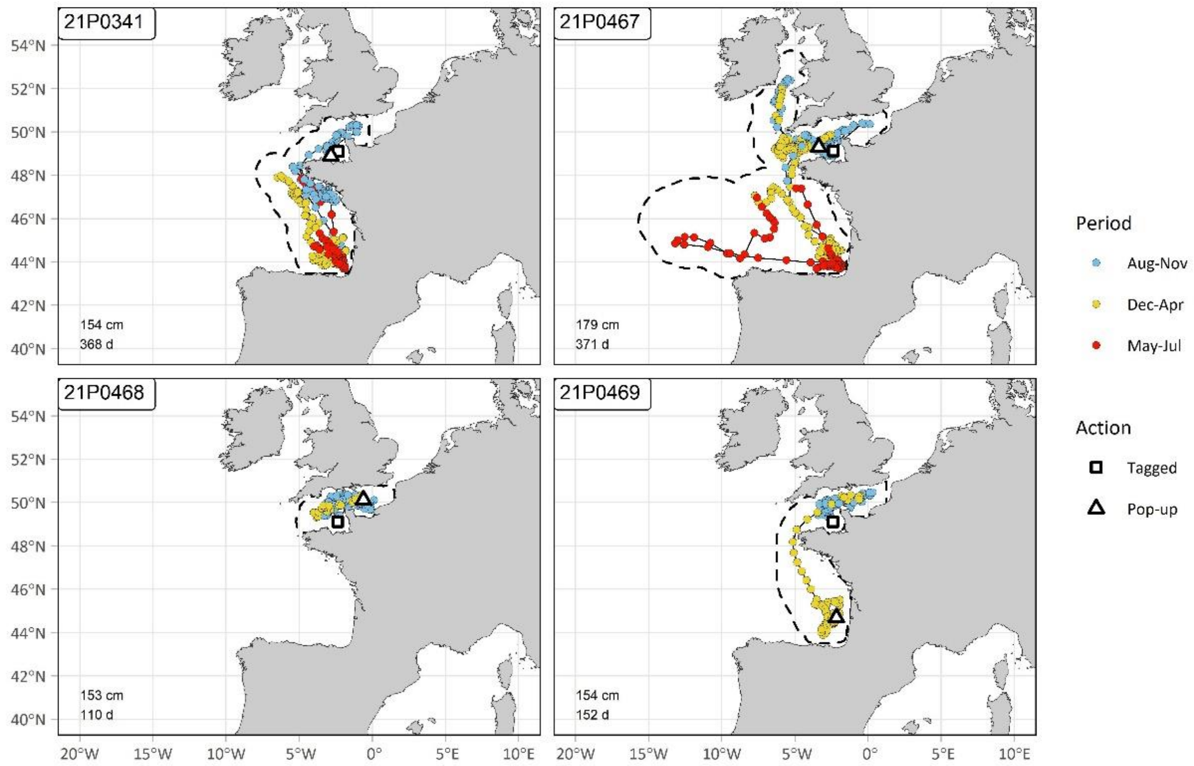

Figure 4. Movements of four ABT with points coloured by seasonal period. Length (CFL) at release and the days at large are shown in the bottom left-hand corner. Dashed polygon represents the 99% probability surface.

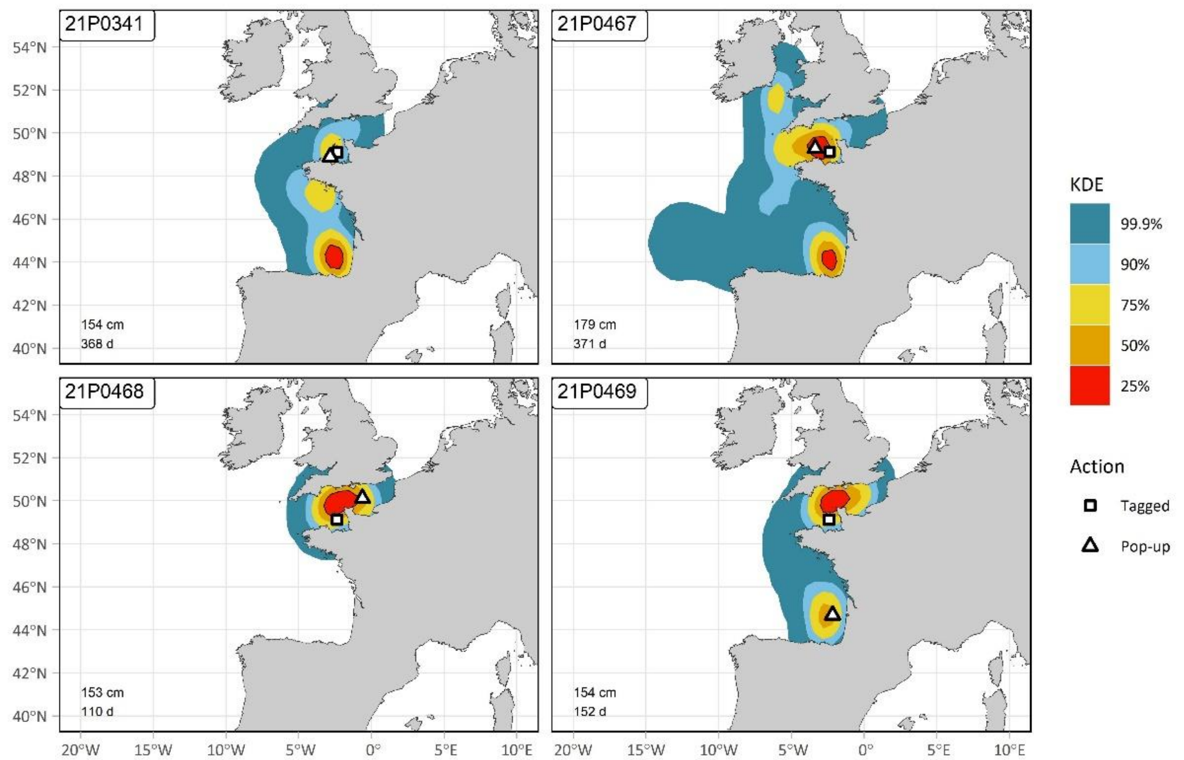

Figure 5. Movements of four ABT summarised as kernel density contours. Length (CFL) at release and the days at large are shown in the bottom left-hand corner.

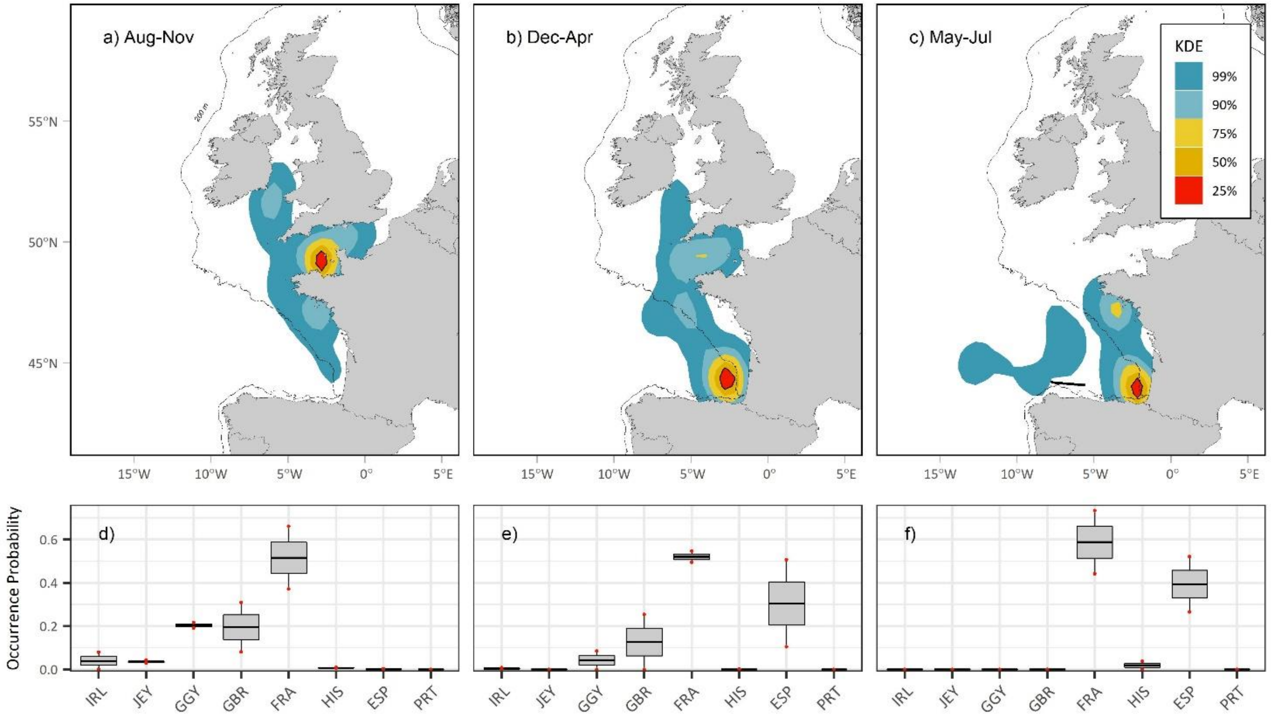

Figure 6. Seasonal movements and geopolitical space use of ABT that were tracked for more than 300 days**.** a-c) Kernel density estimations of modelled daily locations for two ABT in three periods of the year: (a) August to November - late Summer and Autumn, (b) December to April - Winter and Spring, and (c) May to July - late Spring and Summer. (d-f) Boxplots showing occurrence probability for ABT in geopolitical regions (IRL = Ireland, JEY = Jersey, GGY = Guernsey, GBR = Great Britain, FRA = France, HIS = High Seas, ESP = Spain, PRT = Portugal) for respective maps above the boxplots. Red points denote statistically outlying data points.

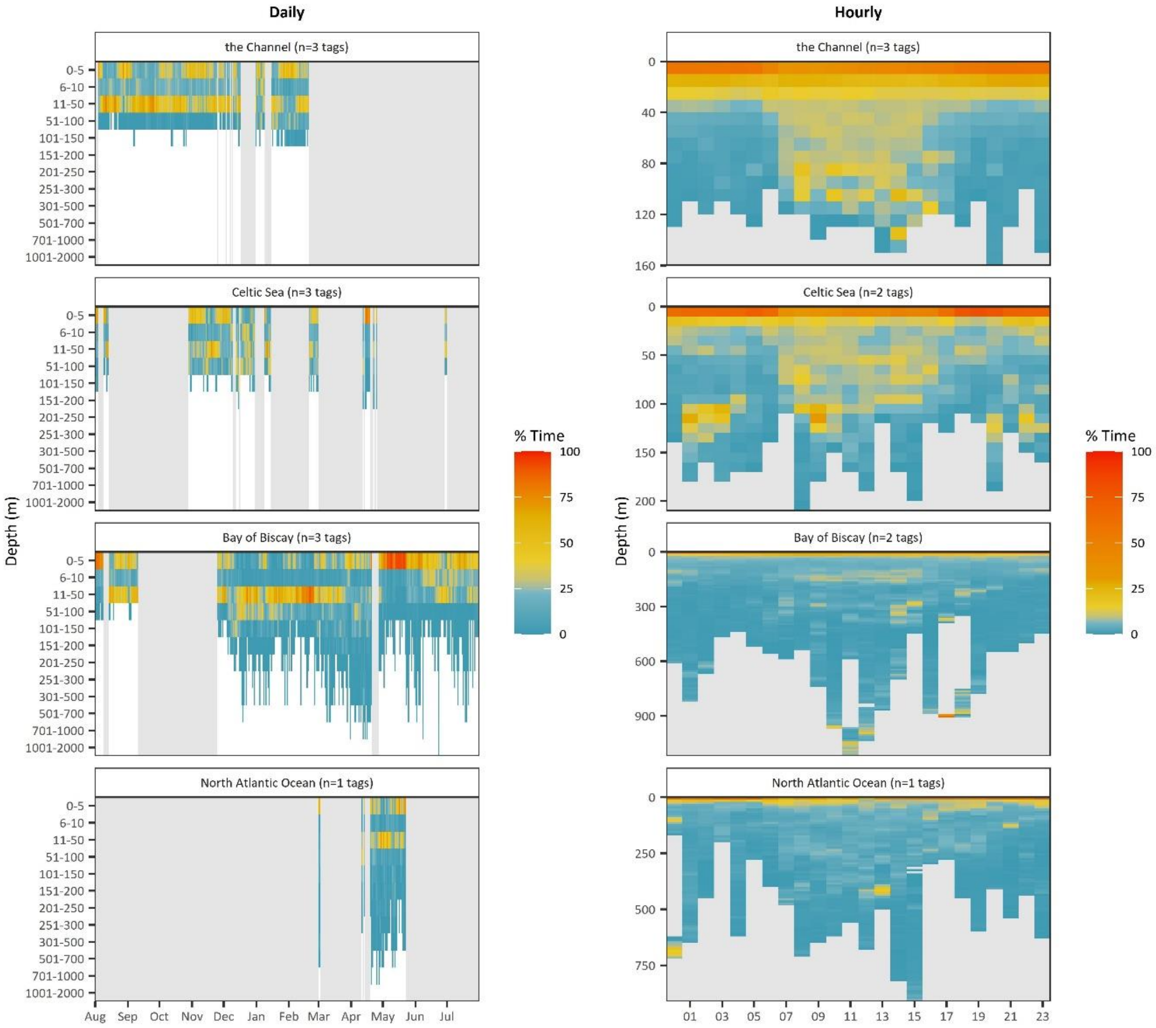

Figure 7. Depth use behaviour by ABT by geographic region. Raster plots showing the proportion of time spent at different depths, summarised for each ecoregion by date. Left column shows daily data from tag remote transmissions, right column shows hourly data from tags that were recovered. Number of tags contributing data to each raster are provided in the label for each plot. Region definitions are provided in **Figure A.1**.

CONCLUSIONS

All Jersey Government funded electronic tags (n=6 MiniPAT and acoustic) were successfully deployed in addition to six ICCAT and two TUK / University of Exeter funded tags (MiniPAT and acoustic), together these will reveal aspects of site fidelity and longer-term behaviour of ABT from Jersey waters. These interim findings will be further developed in 2023 and 2024 once the second batch of MiniPAT tags deployed in 2022 detach and transmit. Acoustic tags should be detected by receivers deployed throughout Channel Island waters and those on the north and south coasts of the Channel bordering France and UK respectively deployed by the EU funded Interreg FCE FISH INTEL project over the next five years.

Data received from the first five MiniPATs that have reported indicate:

1. ABT tracked from Jersey do not leave the Channel ecoregion immediately when released, and instead remain for periods between 54 and at least 111 days.
2. ABT that aggregate off Jersey are mostly (93% of tagged fish; n = 13) smaller individuals between 141 and 179 cm CFL (mean ± 1 S.D. = 165 ± 18), which appear to spend most time in the Bay of Biscay.
3. A single, larger ABT (212 cm CFL) may have visited the Mediterranean Sea, but this is hard to confirm based up on deployment end point alone.
4. Fish spent most time in surface waters at night with proportionally more time spent at depth during the day.

Opportunities for future work

Data detailed here should be included in a scientific publication in preparation by the Thunnus UK team with representative authors from Marine Resources Jersey. In the arena of sustainable management of ABT in Jersey waters, several other lines of data / evidence could be useful, such as:

(i) *Aerial surveys.* Successful management of ABT in Jersey waters will depend on an understanding of how many ABT are simultaneously in Jersey waters. This is best achieved by aerial surveys from light aircraft, that can cover large areas in short periods to avoid the risk of double counting the same fish schools.

(ii) *Public sightings.* An effective public sightings scheme could help to highlight the arrival and departure dates of ABT into Jersey waters, and the spatial range over which they are sighted. Public sightings data are always treated with respect to observer coverage (e.g. Sightings Per Unit Effort, SPUE), but can be valuable to furthering basic understanding.

(iii) *Survivorship tagging.* If a catch-and-release fishery were to begin in Jersey, it would be helpful to understand whether ABT survive after release and what practices promote high survivorship, particularly since this species is usually sought after for a long "fight" by anglers. "Survivorship tags" (also known as sPAT tags) have been specially designed to do this and would inform the optimal fight time, fishing technique and handling strategies to optimise survival.

(iv) *Stakeholder workshops.* Thunnus UK has held several stake-holder workshops to ensure that the diverse voices of the ABT community are considered in future science and planning. A similar endeavour by Government of Jersey could help to direct the success of any management measures.

(v) *Science communication (including animal borne camera work).* ABT are spectacular animals that draw excitement from both the angling and commercial sector as well as from a conservation perspective. A programme of science communication (e.g. video shorts) could help wider education about the species and increase public buy-in for management and fishing strategies, as well as to highlight what may be one of Jerseys premier marine resources.

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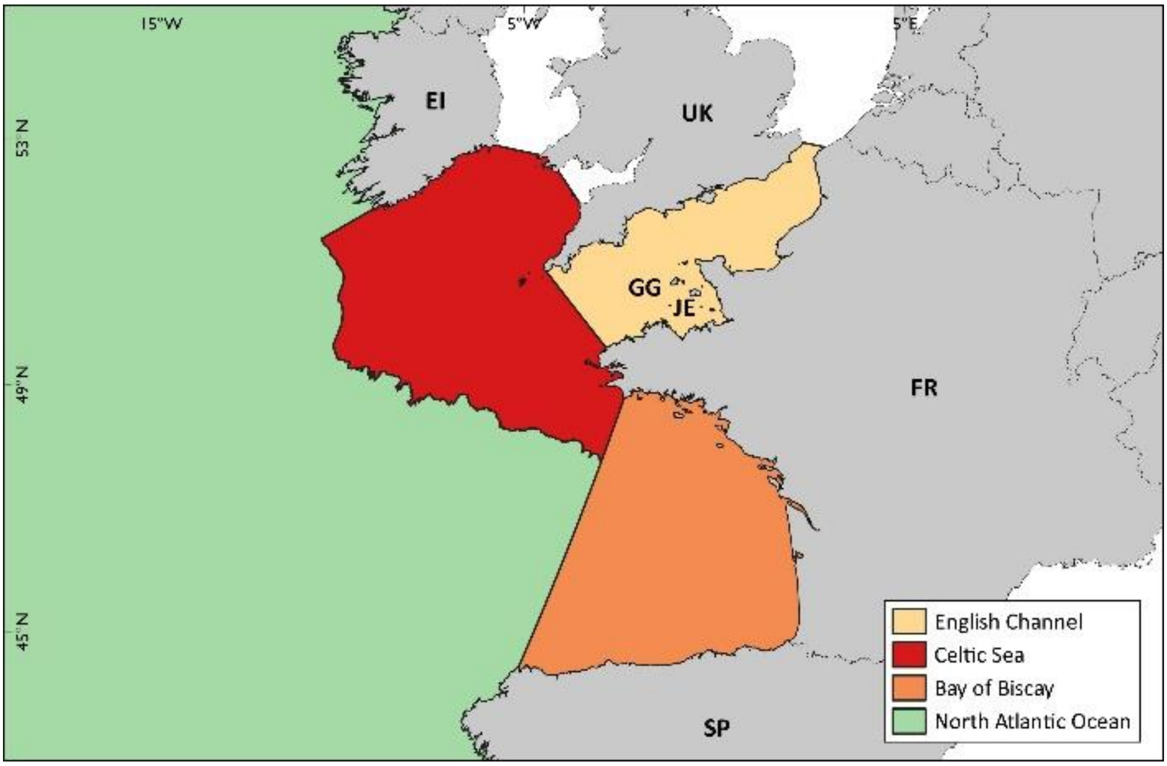

Figure A.1. Spatial definitions of regions referred to in Figure 7.