A simulated archival tagging programme for albacore (*Thunnus alalunga*) in the Northeast Atlantic, including an analysis of factors affecting tag recovery

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An archival tagging programme in the Northeast Atlantic would assist in testing the hypothesis that subpopulations of juvenile albacore exist within the region and provide important information on fish behaviour in relation to environmental variables. No information was available, however, on the ability of juvenile albacore to carry costly implanted archival tags, or on rates of tag recovery. A simulated archival tagging study on albacore using simulated or "dummy" archival tags was therefore carried out in the Bay of Biscay from 2005 to 2008. In all, 353 fish were tagged and released, and 9 fish (2.55%) were recaptured. A comprehensive ICCAT database of conventionally tagged fish in the Northeast Atlantic was also analysed to determine whether optimal conditions at the time of release could be identified and used to boost recovery rates in future tagging programmes. A binary logistic regression model using a response variable with two possible outcomes, recaptured or not recaptured, was developed, then tested on two datasets to deal with association between variables. Effort and fishing gear were significant in the first dataset, and length class and fishing gear in the second. The last two factors can be manipulated, and a recapture rate of >5% was predicted if derived optimal tagging conditions are followed in future tagging programmes.

Keywords: albacore, dummy archival tags, factors affecting recovery, fish behaviour, Northeast Atlantic, subpopulations.

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Introduction

Albacore tuna (*Thunnus alalunga*) are widely distributed in temperate and subtropical waters of all oceans and the Mediterranean Sea. In the North Atlantic, they are an important commercial species, with average annual landings exceeding 30 000 t in the past decade, worth approximately €60 million to fishers each year. European Community vessels accounted for 86% of North Atlantic landings in 2007, with Spain, France, and Ireland the principal nations involved. Baitboat (live) and trolling are the principal fishing methods employed in the North Atlantic, targeting mainly immatures and subadults, and accounting for 67% of the landings in 2007 (Anon., 2008a).

Although North Atlantic fisheries for albacore tuna have remained relatively stable compared with other tuna species, the stock is considered to be overfished, and landings decreased by more than 40% between 2006 and 2007 (Anon., 2008a). MULTIFAN-CL (Fournier *et al.*, 1998; Hampton and Fournier, 2001) and VPA-2 Box (Porch, 2003) models were applied to assess the state of the stock in 2007 (Anon., 2008b). Inputs to the model included standardized catch per unit effort (cpue) indices of various fisheries, but environmental factors, which can have a great effect on catchability (Goni and Arrizabalaga, 2005; Maunder *et al.*, 2006), were precluded from the indices. Enhanced knowledge of fish behaviour in relation to environmental variables, and features such as dissolved oxygen, primary production, and thermal fronts, would assist in developing habitat-based models, which could be incorporated into standardized cpue analyses, leading to fine-tuning of future assessments.

Biological (Aloncle and Delaporte, 1974) and genetic (Brophy *et al.*, 2008) research supports the hypothesis that several independent subpopulations of juvenile albacore exist in the North Atlantic. If proven, this phenomenon would have major implications for the stock assessment process. A coordinated tagging programme on juvenile albacore within proposed subpopulation areas could provide important information in evaluating this hypothesis, ultimately leading to a more robust stock assessment.

Several conventional tagging studies for albacore conducted in the North Atlantic and Mediterranean since the 1960s have provided some information on stock structure; the hypotheses of two separate stocks existing in the North and South Atlantic were supported, long-distance transoceanic movements were confirmed, and limited mixing between the North Atlantic and

Mediterranean was found (Arrizabalaga *et al.*, 2002, 2004). However, this basic mark-and-recapture technique provides limited data on fish behaviour and precludes more detailed analysis of localized stock structure.

Archival tags (electronic data sensors), processors, and storage devices can provide detailed information on fish behaviour. Data on depth, sea temperature, and light level are collected, and an estimated geographic position derived, permitting studies on the effects of the wider environment on fish behaviour. External pop-up archival tags, which transmit data via satellite systems and are therefore fishery-independent, are used extensively in experiments on large pelagic species such as Atlantic bluefin tuna (*Thunnus thynnus*; Block *et al.*, 2005; Stokesbury *et al.*, 2007). New versions of these tags may be small enough to deploy on relatively large albacore, but the duration of attachment and general performance of these tags have yet to be tested on the species. Smaller, internally implantable, archival tags, also known simply as archival tags, can collect data for periods of up to several years, with greater time resolution, and represent the best option for obtaining long-term archived datasets for albacore tuna at present.

Archival tags are, however, fishery-dependent in that tagged fish need to be recaptured to recover the tags and the data. The tags are expensive and, if recovery rates are low, then such experimentation can require major financial investment. In addition, although archival tags have been used extensively for other species of tuna, their use with albacore is relatively new, and no published data are available on the physiological capability of juvenile albacore to successfully carry implanted archival tags. An archival tagging programme has commenced on the west coast of the United States, as part of the Tagging of Pacific Pelagics programme, and 15 archival tags were recovered from 384 deployments, a recovery rate of 3.9%, between 2001 and 2005 (Kohin *et al.*, 2005). Uosaki (2004) reported preliminary results of one recapture from 40 albacore tagged and released with archival tags near Japan. No archival tagging programme for albacore has, however, been carried out in the North Atlantic. Also, the albacore fishery, which is primarily conducted in the Northeast Atlantic, is relatively complex; it is exploited primarily by four nations with four different languages, employing a variety of fishing methods on a highly seasonal basis, potentially complicating the process of recovering tags from recaptured fish.

The purpose of this study, therefore, was to evaluate whether an authentic archival tagging study for juvenile albacore could be carried out successfully in the Northeast Atlantic, which would assist in advancing knowledge of subpopulations and fish behaviour in relation to environmental variables. In addition, an ICCAT database of conventionally tagged albacore was analysed to examine factors at the point of release that subsequently influenced the recovery of tagged fish. Rates of tag recovery for conventional and dummy tagging datasets were not directly comparable owing to differences in the rewards available to fishers for the return of tags. Other factors at the time of release, unaffected by rewards, such as fishing method and fish size, were comparable, however, and it was possible to use modelled probabilities of recapture in relation to factors at the time of release from the conventional dataset as an index of expected probabilities of recapture in relation to those factors in an archival tagging study. In the absence of any historical archival tagging data for albacore in the North Atlantic available for review, this approach attempts to make best use of available tagging data to predict suitable conditions and improve the cost efficiency of future tagging programmes.

Material and methods

Tagging

Dummy tags were based on Lotek LTD2410 archival tags, which were the smallest geolocator and temperature–depth recorders available at the time. The dummies were constructed in plastic moulds from epoxy resin and lead shot to the same dimensions as authentic tags (37 mm long, 11 mm diameter, weight 6.2 g), had a label with contact details embedded, and a protruding monofilament line to imitate the light-sensor stalk. Tagging was carried out in July 2005 and 2006 on board two Irish commercial trolling fishing vessels. Fish were landed in a nylon knotless scoop-net, placed in a cradle with a hose in the mouth to irrigate the gills and were blindfolded with a light sheet of black PVC. An incision was made with a scalpel, 2.5 cm posterior to the pelvic fins, and a gloved finger was used to penetrate the peritoneum. The tag was inserted in the peritoneal cavity and a single surgeon's flat knot was used to seal the wound. Depending on the size of the fish, 1–3 ml of 20% oxytetracycline (OTC) solution was injected into the dorsal musculature of the fish to facilitate age validation, where whole fish were recovered (McFarlane and Beamish, 1987). In 2005, a small quantity of Betamox antibiotic (1–2 ml) was injected into the wound from a syringe without a needle, but this was not repeated in 2006, because it was surmised that the dosage of OTC should provide enough antibiotic. A conventional orange floy tag with contact details was inserted at the base of the second dorsal fin. In all, 353 fish, 199 in July 2005 and 154 in July 2006, were tagged and released in an area in the northwest Bay of Biscay delimited by the coordinates 46–49°N and 7–12°W. A reward of €200 was available to fishers who recaptured and submitted a fish with a dummy archival tag to an appropriate institute.

Analysis of the factors affecting recovery

A conventional tagging dataset provided by ICCAT in July 2008 consisted of tagging release and recapture records for albacore in the North Atlantic and Mediterranean from 1960 to 2007. The database was edited and cleaned to provide a relatively compact dataset, which would permit meaningful multivariate analysis. Minor tagging events of fewer than 40 deployments, incomplete tag recovery records, and duplicate entries were removed. The final dataset consisted of fish released from baitboat and trolling tagging programmes in the Bay of Biscay in the Northeast Atlantic between 1983 and 1991, a total of 13 187 (11 703 baitboat and 1484 troll) release records and 422 associated recaptures.

The edited dataset and other available data were further examined to derive appropriate explanatory variables to be considered in the binary logistic model. A simple fishing effort index was produced; baitboat and trolling are the principal fishing methods employed for albacore in the North Atlantic (Anon., 2008b). Some 95% of recoveries in the dataset were in the first 3 years after release. Annual estimates of standardized fishing effort for these gears (Ortiz de Zarate and Ortiz de Urbina, 2007a, b) were, therefore, combined and cumulated for 3 years after release to provide an effort index. The effort index was clearly bimodal; it was <6300 d from 1983 to 1986 and >12 000 d from 1988 to 1991 (Table 1).

Table 1. Summary of data used in the binary logistic model.

Year	Baitboat releases	Trolling releases	Total effort index (d)
1983	–	277	5 304
1984	–	192	5 932
1985	–	139	5 307
1986	106	103	6 290
1988	–	489	12 882
1989	2 969	40	14 679
1990	4 515	57	13 088
1991	4 113	187	12 265

Independence of the categorical predictor variables was assessed using measures of association. A strong association was observed between gear type and effort level (Goodman–Kruskal's $\lambda = 0.74$; $p < 0.001$). This was due to the disproportionately large number of fish released from baitboats during high-effort years (11 597) compared with low-effort years (106). Two datasets were analysed to deal with this, and the data were reduced by randomly removing the data relating to fish released from baitboat programmes during high-effort years to achieve a balanced dataset. This reduced dataset consisted of a total of 1696 (212 bait boat and 1484 trolling) release records and 87 associated recaptures (Dataset 1). Both the reduced and the original dataset were used in the subsequent analysis for comparative purposes. The model was also applied to a dataset restricted to the years 1988–1991, resulting in a larger dataset of 11 597 baitboat and 773 trolling release records. Bimodal effort distribution was not evident in that dataset, so individual annual total effort indices were included as a continuous variable (Dataset 2), with no association between variables observed.

A binary logistic regression using a binary response variable with two possible outcomes, recaptured or not recaptured, was used to investigate the influence of various factors, at the point of release, on the probability of recapture. The explanatory variables considered in the analysis of the two datasets were:

Categorical:

(i) length class at release [five levels: <55, 55–64, 65–74, 75–84, and >84 cm fork length (L_F)]

(ii) fishing gear used during tagging (two levels: baitboat and trolling)

(iii) month of release (four levels: July, August, September, and October)

(iv) total effort index (two levels: low <6300 d and high >12 000 d)

Continuous:

(i) total effort index.

The basic binary logistic regression model equation can be written as

$$\theta = \frac{e^{(\alpha+\beta 1x1+\beta 2x2+\cdots+\beta ixi)}}{1 + e^{(\alpha+\beta 1x1+\beta 2x2+\cdots+\beta ixi)}},$$

where θ is the probability of success of the dependent variable, in this instance being recaptured, and where α and β are the constant of the equation and the coefficient of the predictor variables, respectively (Hosmer and Lemeshow, 1989). Model fits were evaluated using the Akaike information criterion (AIC; Sakamoto *et al.*, 1986).

Results

Dummy archival tagging

Information on recoveries is summarized in Table 2, and straight-line fish movements are outlined in Figure 1. In all, 9 fish were recaptured from 353 releases, a recapture rate of 2.5%. Five fish were recaptured by live-bait boats, three by pelagic trawlers, and one by a trolling vessel. In total, eight dummy archival tags were recovered. On one occasion, the conventional floy tag was returned but not the dummy archival tag. The fish was sent to a canning factory, and it was not clear if the tag was undetected or had been shed by the fish while at liberty. Eight of the nine recaptured fish were larger when initially released than the mean size of all released fish, i.e. 62 cm L_F. A two-sample t-test for differences in mean size showed that the difference in mean size of all fish released and the subsample of fish released that were subsequently recaptured was significant ($p = 0.025$, $\alpha = 0.95$). The mean growth rate of seven recaptured fish for which size data were available was 8.07 mm month^{-1}, compared with 9.71 mm month^{-1} for recaptured fish from the conventional study within the same size range when released (58–76 cm L_F, $n = 255$).

Table 2. Details of dummy archival tag recoveries.

	Release				Recapture						
		Position				Position					
Tag	Date	N	W	L_F (cm)	Date	N	W	L_F (cm)	Days at liberty	Growth rate (mm month^{-1})	Distance (km)
320	16 July 2005	47°31′23	8°56′30	76	7 July 2006	45°22′00	6°19′00	84	356	6.84	453
327	16 July 2005	47°30′19	8°53′44	64	21 July 2007	44°30′00	3°50′00	80	735	6.62	740
342	17 July 2005	47°58′39	10°00′61	65	31 Oct 2006	–	–	74	471	5.81	–
374	18 July 2005	47°54′25	9°50′32	67	18 Sep 2005	–	–	–	62	–	–
438	20 July 2005	47°55′78	9°38′38	58	21 July 2007	43°47′00	3°47′00		731	–	928
442	20 July 2005	47°57′63	9°43′60	67	23 May 2007	28°31′00	17°38′00	89	672	9.96	2 911
483	22 July 2005	47°57′01	10°00′22	69	10 Oct 2007	49°16′00	11°54′00	89	810	7.51	306
576	23 July 2006	46°56′36	11°55′34	68	08 May 2008	45°11′75	8°25′14	93	655	11.61	480
617	24 July 2006	47°24′23	11°40′73	64	09 Sep 2007	47°47′00	10°00′00	75	412	8.12	197
Mean				66				83	545	8.07	859

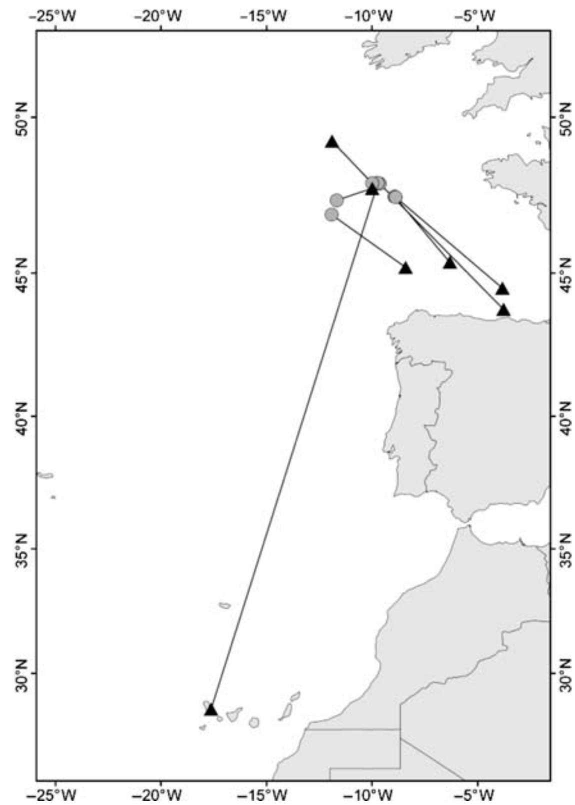

Figure 1. Release (circles) and recapture (triangles) locations of dummy archival tagged albacore tuna.

Factors affecting tag recovery

The results of the binary logistic regression model runs are presented in Table 3. Gear and effort were significant when the model was applied to Dataset 1 ($p < 0.05$), and inclusion of an interaction between gear and effort was not significant and did not improve the model fit (AIC = 679). This analysis showed that fish were almost twice as likely (reciprocal of 0.55) to be recaptured in high-effort years than in low-effort years (odds ratio 0.55, $p = 0.01$). Gear, effort, and length class were all highly significant ($p < 0.01$) when the model was run using the full dataset, ignoring association between variables, demonstrating the loss of the length-class signal in the reduced dataset. Gear and length class were significant and produced the best model fit in terms of AIC (3416) when the model was applied to Dataset 2. Fish in the length class 65–74 cm at the time of release had a higher probability of recapture than all other size classes apart from >84 cm, which was not significantly different ($p = 0.218$). Fish released by the trolling method had a higher probability of recapture than the baitboat releases (odds ratio 0.36, $p < 0.001$). Examination of the basic data showed that recovery rates varied with length at release for fish tagged during baitboat operations, but not for fish tagged during trolling operations. An interaction term between these variables was included in the model, but was not significant and was removed.

In terms of diagnostics, model coefficients for both datasets were significantly different from zero (Dataset 1: $G = 13.487$, $p = 0.001$; Dataset 2: $G = 63.8$; $p < 0.001$). The results of the goodness-of-fit tests (Pearson, deviance, and Hosmer–Lemeshow $p > 0.05$) showed insufficient evidence that the model did not fit the datasets adequately. However McFadden's ρ^2 values were low, 0.017 for Dataset 1 and 0.024 for Dataset 2, demonstrating that only a small part of the variability in the data was described by the model; values of 0.2–0.4 are generally considered to be satisfactory (Hensher and Johnson, 1981).

Discussion

Recaptured dummy archival tagged fish did not move in a straight line and may have made a number of seasonal migrations. One fish was recaptured off the Canary Islands having travelled 2911 km, a relatively long distance compared with the results of conventional tagging studies, where just 4 of 643 recaptured albacore were caught at a distance of >2000 miles (>3220 km) from the point of release (Arrizabalaga *et al.*, 2002). Observed growth rates in dummy and conventionally tagged fish were similar and provide no evidence that the archival tags have a marked effect on growth relative to conventional tags, but a larger sample size is required to confirm this finding statistically.

The limited variability in the edited ICCAT conventional tagging datasets explained by the binary logistic model means that the results should be treated with caution. The model fits to the two datasets were not comparable in terms of AIC values, but the model performed slightly better in terms of explaining the variability of Dataset 2 according to the ρ^2 values.

Analysis of Dataset 1 demonstrated how fishing effort had a significant effect on tag recoveries, with fish almost twice as likely to

Table 3. Results of binary logistic analyses.

						95% bounds		
Predictor	**Estimate**	**s.e.**	**Z**	***p*-value**	**Odds ratio**	**Lower**	**Upper**	**AIC**
Dataset 1								
Constant	−3.70	0.51	−7.22	<0.001				686
Low effort	−0.59	0.23	−2.56	0.010	0.55	0.35	0.87	683
Baitboat	1.12	0.52	2.16	0.031	0.36	1.11	8.42	679
Dataset 2								
Constant	−1.88	0.19	−9.87	<0.001				3 478
<55 cm	−0.97	0.16	−5.93	<0.001	0.38	0.27	0.52	3 450
55–64 cm	−0.52	0.14	−3.61	<0.001	0.59	0.45	0.79	
75–84 cm	−0.72	0.28	−2.52	0.012	0.49	0.28	0.85	
>84 cm	−0.65	0.53	−1.23	0.218	0.52	0.19	1.47	
Baitboat	1.03	0.15	6.67	<0.001	0.36	2.07	3.78	3 416

Reference variables for Dataset 1: high effort and trolling. Reference variables for Dataset 2: 65–74 cm and trolling.

be recaptured in high-effort than in low-effort years, as one would expect from the basic principles of mark–recapture experiments (Quinn and Deriso, 1999). Restriction of the number of tagging releases to just 1696 records in Dataset 1, however, resulted in the removal of a length-class signal from the data, as demonstrated in the application of the model to the full dataset, ignoring association between variables. This was dealt with by applying the model to Dataset 2. Effort was not a significant factor in Dataset 2 because of the similar effort values, but length class and gear were significant, and these are both factors that can be manipulated in future tagging programmes. Optimal tag-and-release size was 65–74 cm L_F, corresponding to ages 2 and 3 years (Santiago and Arrizabalaga, 2005), and fish in that size class were, for example, 2.6× more likely to be recaptured than smaller fish <55 cm L_F, and twice as likely to be recaptured as larger fish in the 75–84 cm L_F class. The decreased likelihood of recapture of smaller fish could be related to catchability issues or stress-related mortality caused by tagging. Fewer returns of larger fish could be explained by those fish diverting on reproductive migrations to parts of the West Atlantic as they sexually matured (Arrizabalaga *et al.*, 2002). Similar trends were observed in the dummy tagging dataset, with eight of the nine fish released that were subsequently recaptured larger than the mean size of all released fish. The mean sizes of these groups were significantly different. The results suggest that focusing tagging effort on fish in the optimal size range 65–74 cm L_F should lead to a boost in recapture rates of archival tagged fish by a factor of ~2, from 2.5 to 5%.

Fish caught and released by trolling were 2.8× more likely to be recaptured than fish caught by pole and line on baitboats, according to the odds ratio in the analysis of Dataset 2. This could be caused by differences in fish-handling techniques intrinsic to the different fishing methods, or possibly more careful selection and improved condition in the considerably lower numbers of troll-released fish. Month was not significant probably because of a concentration of release events in August. Zone was not considered suitable for inclusion in the analysis owing to a restricted area of fish release in the southeastern Bay of Biscay. The overall recapture rate of troll-released fish in high-effort years from the final conventional tag dataset was 7%, compared with 2.5% for the dummy tagging programme. This difference can be explained by the difference in release zones and possibly increased mortality of fish attributable to physiological stress associated with the invasive dummy tagging technique.

To summarize, the results of the dummy archival tagging programme have demonstrated that juvenile albacore in the Northeast Atlantic are physiologically capable of carrying implanted archival tags. Times at liberty, distances travelled, and growth rates of recaptured fish compared well with the results of conventional tagging studies. This suggests that for fish that survive the implanted tag procedure, any impacts on behaviour and physiology associated with the tagging process are no greater for the implantable tagging technique than for the conventional tagging technique. A 5% recovery rate is predicted in future authentic archival tagging programmes by focusing tagging efforts on fish aged 2 and 3 years, i.e. 65–74 cm L_F, caught by trolling, during high-effort years. Restriction of the size of released fish in this manner would be appropriate if the primary objective was to advance knowledge of subpopulations of juvenile albacore. Excluding larger fish would mean that any inferences relating to fish behaviour would generally be restricted to smaller fish, although some data on older fish should be available from long-term deployments. Given the high unit cost of archival tags, however, the loss of information from larger fish is outweighed by the increased probability of recapture of smaller fish. The results of this study suggest that ~200 tags would need to be deployed to obtain a relatively robust sample size of ~10 tag recoveries. Based on the average period of liberty observed here, this would provide more than 5000 days of data, representing a major progression in the knowledge of fish behaviour and stock dynamics of North Atlantic albacore.

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