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Seasonal migration of the starry smooth-hound shark *Mustelus asterias* as revealed from tag-recapture data of an angler-led tagging programme

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The primary aim of this long-term angler-led tagging programme was to gain information about seasonal changes in distribution of the starry smooth-hound shark *Mustelus asterias*, along the Dutch coast for management and conservation purposes. Between 2011 and 2014, *M. asterias* comprised 92·6% ($n = 2418$) of the total elasmobranch catch ($n = 2612$) by the licenced group of taggers within the Dutch Delta of which 2244 *M. asterias* were fin-tagged with plastic rototags. Sex and total length (L_T) composition inside the eastern tidal basin (Oosterschelde) were significantly different, *i.e.* more females and larger individuals, than outside indicating a pupping ground, which was confirmed by the capture of 30 newborn pups (≤32 cm). The distribution pattern of reported recaptured *M. asterias* (return-rate 3·6%, $n = 80$) showed a circannual migration between summering in the southern North Sea and wintering in the English Channel and the Bay of Biscay, and suggests that *M. asterias* is philopatric. The Dutch angling season for *M. asterias* runs from approximately mid-May to mid-October when the water temperature is above 13° C. Recaptures of eight mature females, but no males in the Bay of Biscay, indicate partial spatial segregation by sex, where mature females migrate over larger distances than immature females and males. These observations, with the absence of recaptures in other known summering areas (*i.e.* the Irish Sea and Bristol Channel), suggest that the southern North Sea is used by a separate population. Implications for management and recommendations to improve and expand the study approach are discussed.

Key words: EU action plan on sharks; rototag; shark angling; seasonal migration; Triakidae.

INTRODUCTION

Many elasmobranch species are highly vulnerable to exploitation due to their K-selected life-history strategies (Musick *et al.*, 2000; Stevens *et al.*, 2000). As a consequence, size compositions of elasmobranch populations have been strongly influenced in intensely fished areas such as the southern North Sea (Stevens *et al.*, 2000; Daan *et al.*, 2005; Dureuil, 2013). Bio-geographical changes in the southern

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North Sea due to intensive fishing began as early as the 1920s (Callaway *et al.*, 2007) and at present 63% ($n = 14$) of all elasmobranch species indigenous to the southern North Sea are listed as near threatened, endangered or critically endangered by IUCN, CITES, OSPAR and appear on the Dutch red list.

Following the Code of Conduct for Responsible Fisheries, the European Commission recognized the decline of European elasmobranch populations and published the European Union Action Plan for the Conservation and Management of Sharks (EC, 2009; the EU action plan on sharks). The plan aims to take effective steps to rebuild chondrichthyan stocks (*i.e.* sharks, skates, rays and chimaeras) and sets out guidelines for suitable fisheries (ecosystem-based) management (Murua *et al.*, 2013). This entails modification of a number of existing regulations including science-based, precautionary catch limits for targeted shark fisheries and fisheries with a by-catch of sharks. Despite this, few data are available on elasmobranch biology, distribution, population structure and population sizes in European waters, which makes it difficult to develop effective fisheries management measures (Vas, 1995; Fowler *et al.*, 2005).

Fisheries research often focuses on high value commercial species (Jennings *et al.*, 2001) but apart from the spiny dogfish shark *Squalus acanthias* L. 1758 for which fisheries are now closed due to overexploitation (Fordham *et al.*, 2006), targeted commercial elasmobranch fisheries in the southern North Sea are rare (Gibson *et al.*, 2008). Elasmobranchs are taken as by-catch, but are often discarded and unreported (Vas, 1995; Musick *et al.*, 2000), hence their abundance and distribution within this area are largely unknown and the information available is mostly from limited survey data. Anglers target and catch elasmobranchs along the Dutch coastline and this may provide a valuable data source about elasmobranch populations in this area. From 2009 onwards, anglers identified several locations within the Dutch Delta where elasmobranchs, predominantly the starry smooth-hound shark *Mustelus asterias* Cloquet 1819, were seasonally abundant (Fig. 1).

Until recently little was known about the biology and ecology of *M. asterias* in the north-east Atlantic region, which was due in part to the difficulty in distinguishing it from the common smooth-hound *Mustelus mustelus* (L. 1758) (Farrell *et al.*, 2009). Development and wide-scale deployment of a genetic identification method, however, have indicated that *M. asterias* is probably the only species of *Mustelus* in this region (Farrell *et al.*, 2009; Farrell, 2010). The length and age at maturity in the north-east Atlantic Ocean were subsequently estimated at 78 cm total length (L_T) and 4–5 years and 87 cm L_T and 6 years, for males and females (Farrell *et al.*, 2010*a*, *b*) with longevity estimated as 13·0 and 18·3 years for males and females, respectively (Farrell *et al.*, 2010*a*). *Mustelus asterias* has a special crushing dentition and feeds primarily on crustaceans, in particular portunid crabs (Ellis *et al.*, 1996), which are often abundant in sandy inshore areas. Information on population structure within and between the north-east Atlantic region and the Mediterranean Sea is scarce; however, geographic variation in key reproductive characteristics has been noted between these areas (Farrell *et al.*, 2010*b*).

Spatial management, which is one of the aims of the EU action plan on sharks, requires an improved knowledge of population structure and habitat utilization including the location of important life-history stages such as pupping and nursery grounds (Heupel *et al.*, 2007; Martin *et al.*, 2010). Insight into movement and migration patterns can contribute to the development of effective management and conservation strategies for these species and help identify areas of critical habitat.

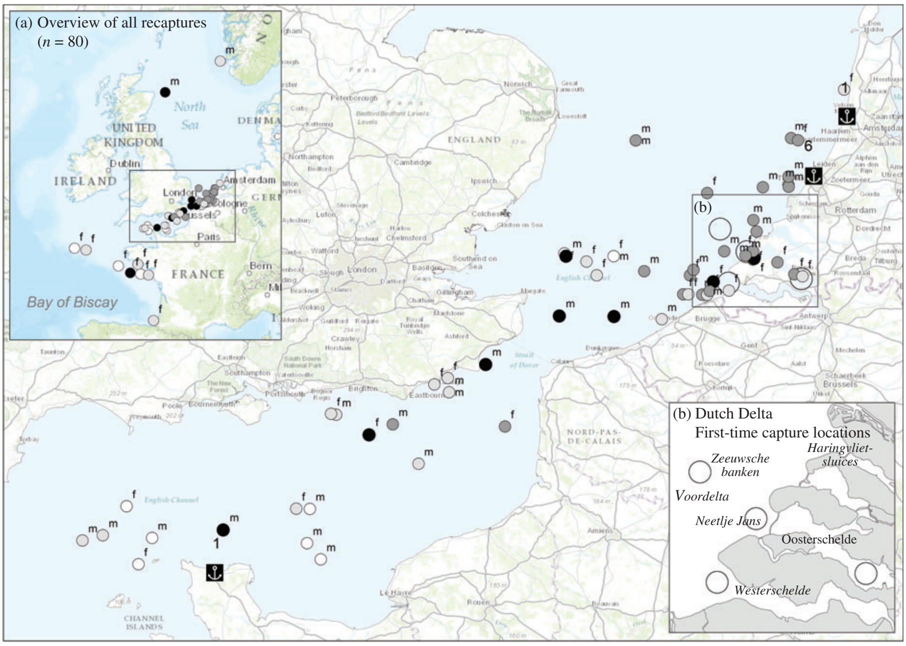

Fig. 1. Study area. (a) The locations of all reported recaptured *Mustelus asterias* ($n = 80$) presented per quarter of a year from 4 years (2011–2014). Their distribution pattern indicates a circannual migration between the Dutch Delta (summer), the English Channel and the Bay of Biscay (winter). The full map shows the distribution of recaptures in some detail within the English Channel and the southern North Sea. From three fish markets (harbours are indicated with anchors), eight tagged *M. asterias* were reported (numbers next to the anchors represent the number of sharks from each fish market) with unknown recapture location. (b) The area where all *M. asterias* from this study have been captured, tagged and released; the main places fished are roughly indicated with open circles and named. f, female; m, male; recaptures per quarter of a year: ○, January to March; ○, April to June; ●, July to September; ●, October to December.

In 2011, Sportvisserij Nederland in conjunction with the fisheries research institute IMARES, Wageningen UR, initiated a tagging programme with anglers in the Dutch Delta. The primary aim of the programme was to collect data on *M. asterias* in Dutch waters including life-history parameters, seasonal changes in distribution and identification of sites where important life-history stages occur such as pupping grounds. The second aim was to increase public awareness and to educate anglers and commercial fishers about the necessity of careful handling and release of elasmobranchs, in order to reduce mortality and enhance recovery. This study reports the progress of the tagging programme and seasonal migration of *M. asterias* between the southern North Sea and the Bay of Biscay, as revealed from tag-recapture data.

MATERIALS AND METHODS

STUDY AREA

All elasmobranchs within the tagging programme were captured, tagged and released in the Dutch Delta area (south-west Netherlands) [Fig. 1(b)]. This area is part of the Zeeuwse banken (Natura 2000 H1110 area) and includes the Oosterschelde (Natura 2000) and the Westerschelde (eastern and western Scheldt tidal basins): two sea-inlets that reach *c.* 40 km inland. Water depth within the tidal basins varies between 2 and 30 m and the topography comprises troughs, sand waves and mega ripples, which are partially mined for sand (Cleveringa *et al.*, 2012). Due to the naturally high physical dynamics of the area, there is a relatively low number of benthic species (Cleveringa *et al.*, 2012). The area is connected to a similar series of sand banks and troughs in the south called the Zeeland banken, which are within Belgian waters.

CATCHING AND TAGGING METHODS

The tagging group consisted of 13 recreational angling charter skippers, two private boats (all vessels <12 m long) and a family of artisanal fishers specializing in European anchovy *Engraulis encrasicolus* (L. 1758) in the Oosterschelde. Elasmobranchs were caught with rod-and-line, usually baited with the ragworm *Alitta virens*. Typically, angling was conducted on days with wave-heights of <1 m and wind forces below Beaufort force five. Although the tagging group fished year round within the Dutch Delta whenever these conditions were met, it was not possible to calculate their catch per unit effort as days fished and numbers of rods fished were not recorded. The anchovy fishers fished from May to July and used a weir set-up with three fykes at set locations.

All licenced taggers were instructed on identification, tagging and handling procedures and provided with tagging kits each year at the start of the *M. asterias* fishing season in May. In order to minimize stress and potential damage to specimens, up-tide fishing by rod-and-line, which allows the use of self-hooking systems with small harp hooks, and landing-nets of all elasmobranchs was employed thus avoiding lifting individuals by the hook or tail. This fishing technique was originally designed to capture demersal fish species such as Atlantic cod *Gadus morhua* L. 1758, whiting *Merlangius merlangus* (L. 1758), dab *Limanda limanda* (L. 1758) and sole *Solea solea* (L. 1758), but it proved an effective method to capture bottom foraging elasmobranchs as well. Catch-and-release fishing was strictly followed. For each elasmobranch caught, the species, sex, L_T (cm) and mass (M, kg), together with details of catch co-ordinates, location-description, date, time and contact information (of the angler or client) were recorded and pictures of the specimen were taken.

The rototags used in this study comprised two-piece sheep ear tags (Oberarch Patents, Ltd; www.dalton.co.uk); mass: 1·7 g; height: 10 mm; width: 35 mm; laser print male side: serial number (five digits with leading zeros); laser print female side: www.sharkray.eu. Rototags were applied in the first dorsal fin but *M. asterias* individuals <40 cm L_T were not tagged as their fins could potentially be damaged by the tags. In 2013 and 2014, the participating anchovy fishers and anglers were provided with the larger but similar Jumbo Rototags (mass: 3·1 g, height: 10 mm and width: 45 mm) because they encountered full grown female *M. asterias* and several tope shark *Galeorhinus galeus* (L. 1758) with thicker dorsal fins, especially within the Oosterschelde. All tagging was performed under license of the Dutch Animal Welfare Act (project reference 2013170.a.).

Upon recapture of the elasmobranch, all fishers were requested to record and provide the tag number, the condition of the individual, the tag and the tagging wound, together with details of the recapture location co-ordinates, date, sex, L_T (cm) and M (kg), the fishing gear used, and to provide pictures of the recaptured individuals. In return, first-time capture information (including time elapsed since tagging, growth, location and general information on the programme) was forwarded to the re-captor, along with a choice between a monetary reward or T-shirts for the crew.

DATA ANALYSIS

The statistical package R (R Core Team; www.r-project.org) was used for all data analyses.

First-time captures within the Dutch Delta

Due to the unreliability of external characteristics (*i.e.* the presence or absence of white spots) for species identification between *M. asterias* and *M. mustelus* and the confusion regarding the identification of specimens with faint or absent spots (Farrell *et al.*, 2009; Farrell, 2010), genetic samples were collected from ambiguous specimens. Fin clips were cut from the trailing edge of the second dorsal fin from 38 specimens in 2013 and 38 specimens in 2014 for genetic identification, following Farrell *et al.* (2009). The seasonal distribution of captures was analysed in relation to seawater temperature at the Haringvliet sluices (downloaded from www.rijkswaterstaat.nl/water).

It is assumed that the L_T of the individuals in each (age) group was normally distributed around the mean L_T of that specific group according to: $f(x, \mu, \sigma) = \left[\sigma\sqrt{(2\pi)}\right]^{-1} e^{-[(x-\mu)^2(2\sigma^2)]-}$, where f is frequency, x is length, μ is mean length and σ is S.D. A normal expectation-maximization (EM) algorithm for normal mixtures (*normalmixEM* function within the 'mixtools' package in R) was applied to the L_T frequency data to decompose this mixture of normally distributed groups into different components, under the assumption that growth remained constant throughout the sampling period. Nested models, *i.e.* with three, four, five and six components, were run in order to determine the optimal fit. Based on the AIC, the length frequency data could best be separated into six components.

The relationship between M and L_T was calculated for males and females by fitting data to the power equation $M = aL_T{}^b$, where M is in kg, L_T is in cm, a the intercept and b the slope. In order to determine whether sex and L_T were dependent on location (*i.e.* inside or outside the Oosterschelde), a binomial generalized linear model was run where location was the dependent variable and the effects of sex, L_T and the interaction between sex and L_T were tested. Observations of individuals were only included in the analysis when sex was known. To find the optimal set of variables, a forward selection was applied.

Recaptures

In order to visualize the seasonal distribution patterns of reported recaptures of *M. asterias*, a map of each recapture location was generated in ArcGIS Desktop 10 (www.esn.com). The longest distance travelled along the coastline was estimated using Google maps.

A χ^2 test was used to determine whether the sex distribution of recaptured *M. asterias* was independent of location in either the Bay of Biscay, the English Channel or the North Sea. Thereafter, a *post hoc* test of independence was run to test which location, if any, showed a significantly different sex distribution.

Photographs of the tags on recaptured individuals were visually analysed to determine whether any infection, due to the tag and biofouling on the tag, had occurred. The number of photographs was too small to statistically analyse whether or not a pattern existed between days-to-recapture and the presence or absence of infection and/or biofouling.

Publicity and public awareness

As the quantity (and quality) of the results relied on the physical recovery of the tags, good publicity about the tagging programme was deemed essential. A website providing information on the programme was developed (in Dutch: www.haairog.nl and in English and French: www.sharkray.eu) and was supplemented with downloadable fact-sheets provided by the Shark Trust (www.sharktrust.co.uk). For identification and publicity purposes, a special ID-card of all shark, skate and ray species endemic to the southern North Sea was developed in both Dutch and English. The ID-card was distributed in December 2011 by the Ministry of Economic Affairs at all Dutch fish auction markets and to commercial fishers, and the ID-card was widely distributed amongst anglers and the charter skippers by Sportvisserij Nederland (and made available at www.sportvisserijnederland.nl). Further publicity was generated by a fishing event SHARKATAG, following the example of the Scottish Sea Angling Conservation Network (SSACN): during 3 days *c.* 100 VIPs and 300 regular anglers went fishing with the skippers, specifically for shark tagging. The event received extensive national media coverage, which raised more public awareness of the necessity to conserve elasmobranchs.

RESULTS

FIRST-TIME CAPTURES WITHIN THE DUTCH DELTA

In four seasons, 2011–2014, a total catch of 2612 elasmobranchs of five species was recorded, of which *M. asterias* represented 92·6% of the total catch (Table I). The

TABLE I. Numbers of first-time captures (tagged and not tagged) of elasmobranchs within the Dutch Delta between 2011 and 2014. Not all individuals were tagged, *i.e.* rototags and jumbotags were not ideal for tagging *Mustelus asterias* <40 cm total length (L_T) and *Raja clavata*

Species	2011	2012	2013	2014	Total	% of total
Tagged (*n*)						
R. clavata	0	0	0	0	0	0·0
Dasyatis pastinaca	0	2	5	2	9	0·4
Galeorhinus galeus	0	11	9	13	33	1·4
Scyliorhinus canicula	14	6	25	46	91	3·8
M. asterias	176	478	860	730	2244	94·4
Total	190	497	899	791	2377	
Not tagged (*n*)						
R. clavata	0	0	1	1	2	0·9
D. pastinaca	1	11	4	38	54	23·0
G. galeus	0	0	0	0	0	0·0
S. canicula	4	1	0	0	5	2·1
M. asterias	73	23	55	23	174	74·0
Total	78	35	60	62	235	
Total captured (*n*)						
R. clavata	0	0	1	1	2	0·1
D. pastinaca	1	13	9	40	63	2·4
G. galeus	0	11	9	13	33	1·3
S. canicula	18	7	25	46	96	3·7
M. asterias	249	501	915	753	2418	92·6
Total	268	532	959	853	2612	

fin clip samples were all positively genetically identified as *M. asterias*. Other elasmobranch species caught were lesser spotted dogfish *Scyliorhinus canicula* (L. 1758) ($n = 96$), common sting ray *Dasyatis pastinaca* (L. 1758) ($n = 63$), *G. galeus* ($n = 33$) and thornback ray *Raja clavata* L. 1758 ($n = 2$). The number of captures and recaptures of the other elasmobranch species (Tables I and II) was too small to analyse further and these were omitted from subsequent analyses.

The season for *M. asterias* rod fishing in the Dutch Delta runs from approximately mid-May to mid-October (Fig. 2). The earliest and latest capture dates in the four

TABLE II. Number (*n*) and per cent of reported recaptured elasmobranchs per year and in total between 2011 and 2014

	Recaptured [*n* (%)]				
Species	2011	2012	2013	2014	Total
Raja clavata	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)
Dasyatis pastinaca	0 (–)	0 (–)	0 (–)	0 (–)	0 (–)
Galeorhinus galeus	0 (–)	2 (18·2)	0 (10·5)	1 (9·7)	3 (9·7)
Scyliorhinus canicula	0 (–)	0 (–)	1 (2·2)	1 (2·2)	2 (2·2)
Mustelus asterias	1 (0·6)	8 (1·4)	29 (2·5)	42 (3·6)	80 (3·6)
Total	1 (0·5)	10 (2·0)	30 (3·3)	44 (5·6)	85 (3·6)

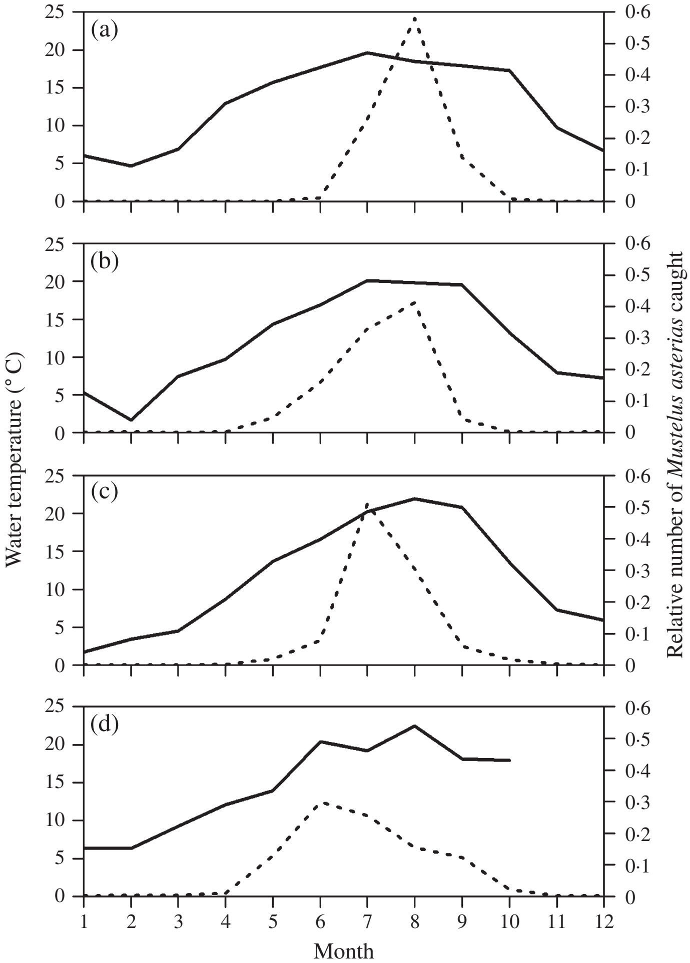

FIG. 2. Monthly data on water temperature at Haringvliet sluices (———, source: www.rijkswaterstaat.nl/water) and relative number of *Mustelus asterias* caught (········) for (a) 2011, (b) 2012, (c) 2013 and (d) 2014.

study years both occurred in 2014: 22 April and 25 October, respectively. Catches were nearly absent when the water temperature was below 13° C (Figs 2 and 3). Variation in seasonal distribution of catches between years was relatively low, although a comparatively very warm June in 2014 coincided with earlier high catches of *M. asterias*. A more detailed view of captures per week showed that immature males and females displayed a similar seasonal pattern between week 17 (April) and 41 (October) [Fig. 4(a)]. Mature males arrived in the fishery prior to mature females between week 20 and 23 (May to June) [Fig. 4(b)]. Newborn pups (≤32 cm L_T) occurred between week 29 and 35 (July to August) [Fig. 4(b)] and during this period fewer mature females were captured [Fig. 4(b)].

The L_T frequency analysis showed that the L_T data collected during the period 2011–2014 can be best separated into six components, based on the AIC (Table III and Fig. 5). The largest male and female *M. asterias* captured had an L_T of 122 and 130 cm, respectively.

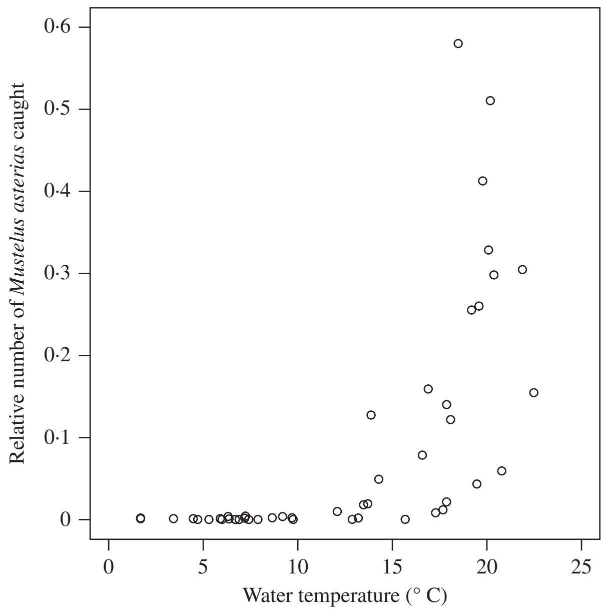

FIG. 3. Recorded temperature at Haringvliet sluices and the proportion of *Mustelus asterias* caught by month.

The mass to L_T relationships for *M. asterias* were described by the following equations and were comparable with those reported by Farrell *et al.* (2010*a*) (Fig. 6), $M = 1 \times 10^{-5}\ L_T^{2\cdot71}$ ($r^2 = 0\cdot93$) for males and $M = 8 \times 10^{-6}\ L_T^{2\cdot81}$ ($r^2 = 0\cdot94$) for females. The sex ratio of adults at the Zeeuwse banken [Fig. 1(b)] was *c.* 1:1 for *M. asterias* under 100 cm. For larger sharks (>100 cm L_T), however, this ratio increased to 4:1 females to males (Table IV).

The optimal set of variables for the binomial generalized linear model includes sex and L_T. The model showed a significant difference between sex and L_T composition inside and outside the Oosterschelde (Table V), *i.e.* more females and larger individuals inside the Oosterschelde than outside (Fig. 7). The interaction between sex and L_T was not significant ($P > 0\cdot05$).

REPORTED RECAPTURES

As of 31 December 2014, a total of 80 (3·6%) tagged *M. asterias* were recaptured and reported (Table II). Most recaptured individuals were found in the English Channel and the North Sea. No individual had been recaptured twice. In total, 35 recaptures were reported *via* (fisheries) institutes from four countries: Netherlands, IMARES (15); France, IFREMER (6), Lycee Maritime Cherbourg (6) and National History Museum (2); U.K., CEFAS (2) and Marine Scotland (1); Belgium, ILVO (3). Thirty-seven recaptures were directly reported by commercial fishers or fish markets from seven nationalities: Netherlands (15), France (10), Denmark (5), U.K. (4), Norway (1), Belgium (1) and Spain (1). From all recaptures, 75% ($n = 60$) of individuals were reported dead. All eight recaptured *M. asterias* caught by the tagging group were released alive. Dutch commercial fishermen released 30% ($n = 9$) of recaptured *M. asterias* alive, whilst commercial fishers from other countries only released 7% ($n = 3$) alive.

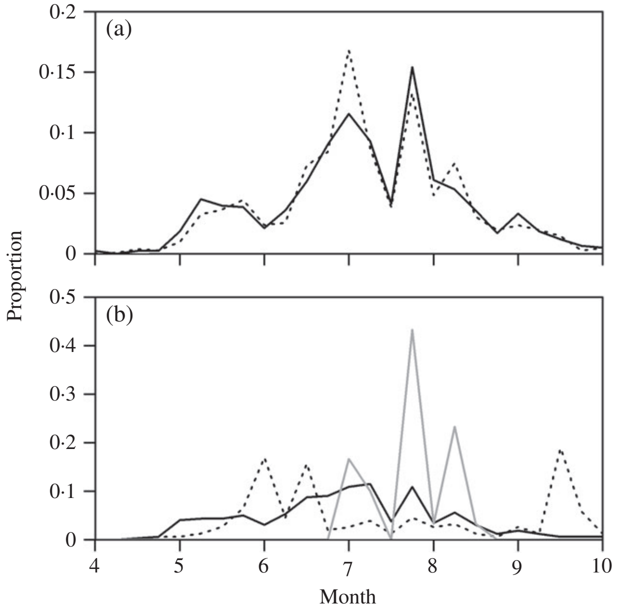

FIG. 4. Proportion of captures in the Dutch Delta between 2011 and 2014 per week of (a) immature *Mustelus asterias* [——, males >32 and <78 cm total length (L_T) ($n = 756$); - - - -, females >32 and <87 cm L_T ($n = 1016$)] and (b) mature and newborn *M. asterias* [——, males ≥78 cm L_T ($n = 322$); - - - -, females ≥87 cm L_T ($n = 155$); ——, pups ≤32 cm L_T ($n = 30$)].

The longest recorded time-at-liberty in this study was 746 days and the longest distance travelled was *c.* 1400 km for a female recaptured at 43° 44′ 20·0″ N; 1° 53′ 20·0″ W in Arcachon, France (Fig. 1). Within the study area, 20 tagged *M. asterias* were recaptured between 313 and 441 days at liberty. The circannual migration pattern of *M. asterias* is illustrated by mapping recaptures by quarter of a year (Fig. 1).

Most recaptured individuals were caught in the North Sea. The sex distribution of recaptured *M. asterias* differed significantly between three locations: the North Sea, the English Channel and the Bay of Biscay ($\chi^2 = 8·5734$, d.f. = 2, $P < 0·05$).

TABLE III. Computed mean ± S.D. total length (L_T) by component of the optimal fit of normal EM algorithm on *Mustelus asterias* L_T frequency data collected in the Dutch Delta during the period 2011–2014 ($n = 2342$)

Component	L_T (cm)
1	28·3 ± 2·2
2	37·3 ± 5·0
3	53·9 ± 4·1
4	67·1 ± 4·8
5	78·8 ± 8·7
6	101·5 ± 16·8

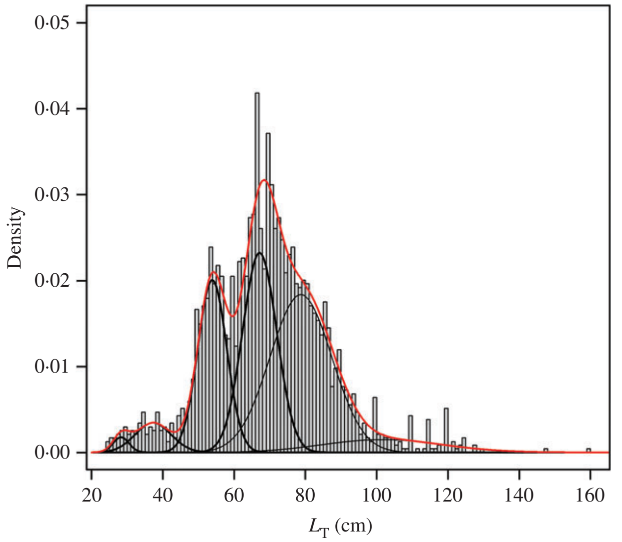

FIG. 5. Relative total length (L_T) frequency distribution of *Mustelus asterias* collected in the Dutch Delta during the period 2011–2014 ($n = 2342$) separated into six normally distributed components (——) and corresponding mixed distribution (——).

A *post hoc* test of independence was run to test the pair-wise comparisons with the Bonferroni-adjusted *P*-value adjusted to 0·017 (*i.e.* 0·05/3) as there were three comparisons. The results indicated that more females were caught in the Bay of Biscay, France (eight females and no males) and this significantly differed ($P < 0·05$) from the North Sea where equal numbers of males and females were caught (22 females and 25 males). There was no significant difference, however, in the sex composition of recaptures between the Bay of Biscay and the English Channel ($P > 0·05$; nine females and 12 males) nor the English Channel and the North Sea ($P > 0·05$).

Photographs were available for 25 recaptured individuals. For 20 individuals, the photographs were of sufficient quality to visually determine whether any infection due to the tag and biofouling on the tag had occurred. For 10 individuals, an infection and biofouling was identified (see photograph examples in Fig. 8). Overall, no indication of a pattern was found between the days-to-recapture and the presence or absence of infection and biofouling.

It is notable that a recaptured female *M. asterias* dissected at IFREMER contained four unborn pups, two in each uterus. The *M. asterias* was tagged on 12 July 2012 and had grown by 6·5 cm (from 90·5 to 97 cm L_T) and 0·38 kg (from 2·89 to 3·27 kg) during the 321 days at liberty.

DISCUSSION

DISTRIBUTION PATTERNS

This is the first study on the seasonal distribution of *M. asterias* based on tagging data in the north-east Atlantic Ocean. These primary findings show that the Dutch Delta

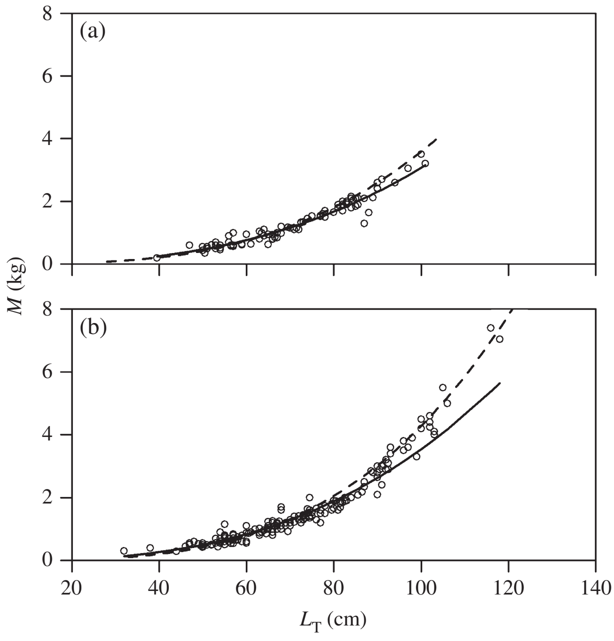

FIG. 6. The total length (L_T) and mass (M) relationships for captured (not recaptured) (a) male ($n = 90$) and (b) female ($n = 163$) *Mustelus asterias*. ——— are fitted through the data of this study and ········ represent the L_T and M relationships as found by Farrell *et al.* (2010*a*). The corresponding equations are respectively: (a) $y = 1E\text{-}05x^{2·714}$ ($r^2 = 0·9322$) and $y = 3E\text{-}06x^{3·0525}$ ($r^2 = 0·9803$) and (b) $y = 8E\text{-}06x^{2·818}$ ($r^2 = 0·9348$) and $y = 1E\text{-}06x^{3·2737}$ ($r^2 = 0·9828$).

plays an important part in the life-cycle of this species from approximately mid-May to mid-October. The Dutch Delta is a geographically discrete, shallow, high energetic region and an area where gravid female sharks can give birth to pups and where the pups can develop. Ellis *et al.* (2005*a*, *b*) noted that shallow coastal areas are suitable pupping grounds for *M. asterias*. The results of this study support this as the proportion of larger mature individuals and female *M. asterias* was significantly higher in the Oosterschelde (Fig. 7). In addition, 30 newborn pups were found at the surge barrier Neeltje Jans, just outside the Oosterschelde (Fig. 1).

Throughout the season, weeks 17–41 (April to October), immature males and females occurred in near equal proportions [Fig. 4(a)]. Mature males arrived *c.* 2 weeks earlier than mature females [Fig. 4(b)] and the capture of mature females decreased just before the pups were captured in approximately week 29 (July) [Fig. 4(b)]. In this study, one recaptured female *M. asterias* was reported with four unborn pups, which is in agreement with the previous reported fecundities for this species of six to 18 embryos (Farrell *et al.*, 2010*b*) and four to 20 embryos (McCully Phillips & Ellis, 2015).

The recorded migration trend between the southern North Sea in summer and the English Channel and the Bay of Biscay in winter (Fig. 1) confirms *M. asterias* as a northern species endemic to the north-east Atlantic Ocean (Ebert *et al.*, 2013). The recapture data also suggest a partial spatial segregation by sex. Eight mature females (but no males) were reported from the Bay of Biscay and two males (but no females)

TABLE IV. Number (*n*) and per cent of captured (not recaptured) male and female *Mustelus asterias* in the Dutch Delta per total length (L_T) class of 10 cm

	n				%		
L_T (cm)	Male	Female	Unknown	Sum	Male	Female	Unknown
Unknown	2	4	4	610	3	7	90
11–20	0	2	2	2	0	100	0
21–30	7	11	11	29	24	38	38
31–40	26	36	36	70	37	51	11
41–50	61	64	64	127	48	50	2
51–60	200	226	226	434	46	52	2
61–70	297	296	296	612	49	48	3
71–80	232	308	308	557	42	55	3
81–90	196	133	133	337	58	40	2
91–100	58	47	47	110	53	43	5
101–110	9	30	30	39	23	77	0
111–120	2	25	25	27	7	93	0
121–130	1	12	12	13	8	92	0
Total	1091	1194	1194	2418	45	49	6

were reported from the northern North Sea (Fig. 1). This could indicate that mature females overwinter in the southern Bay of Biscay and then return to parturition grounds in the north. Males may intercept them and breed as they are passing. Francis (1988) reported a similar pattern for the spotted estuary smooth-hound *Mustelus lenticulatus* Phillipps 1932 in New Zealand, where mature females migrated over longer distances than males and immature females. The spatial segregation by sex is something to be investigated further by future research with larger sample sizes.

The specific circannual migration pattern within a defined geographical area and the lack of recaptures in other summer grounds, including the Irish Sea and Bristol Channel (Fig. 1), may also suggest the structuring of the population within the north-east Atlantic Ocean. Data indicate that *M. asterias* is philopatric and since *M. asterias* is also abundant in the Irish Sea, the Celtic Sea, the Bristol Channel and the North Sea (Farrell *et al.*, 2009) this implies the existence of two (or more) populations in the north-east Atlantic Ocean. If this is the case, then these populations might have different demographic parameters (dispersal, growth, natality and mortality), showing self-sustaining

TABLE V. Change in deviance and corresponding χ^2 values for the optimal set of variables found in the binomial generalized linear model

Variable to be dropped	d.f.	Deviance	AIC	LRT	Pr (χ^2)
<none>		308·89	314·89		
L_T	1	644·04	648·04	335·15	<0·001
Factor sex	1	319·39	323·39	10·50	0·001

L_T, total length.

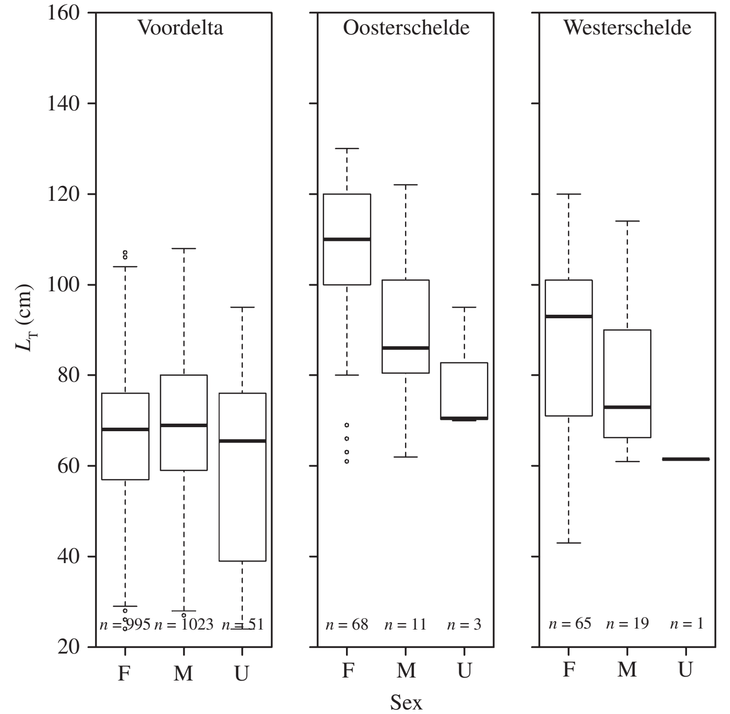

FIG. 7. Boxplots of total length (L_T) measurements of *Mustelus asterias* individuals caught within the Voordelta (Neeltje Jans and Zeeuwse banken), Oosterschelde and Westerschelde [see Fig. 1(b) for locations]. F, females; M, males; U, unknown. Upper whisker represents min(max(×), Q3 + 1·5 × IQR); lower whisker represents max(min(×), Q1 − 1·5 × IQR), where inter-quartile range (IQR) = Q3 − Q1, the box length. So the upper whisker is located at the 'smaller' of the maximum × value and Q3 + 1·5 × IQR, whereas the lower whisker is located at the 'larger' of the smallest × value and Q1 − 1·5 × IQR. Q represents quartile. The ○ represents any data not included between the whiskers and plotted as an ⊢--□--⊣. ___ represents median.

capacity and must therefore be treated as a separate management units (Gulland, 1983; Gayanilo *et al.*, 2005). It is, however, outside the scope of this study to estimate these stock-parameters including stock size. Therefore, further research on a larger scale is recommended, including genetic stock identification techniques.

LENGTH AND MASS FREQUENCY

A comprehensive analysis of age and growth estimates has already been reported by Farrell *et al.* (2010*a*, *b*). L_T frequency data analysis of captured specimens in this study identified six components (Table III) that could be attributed to an age group; however, these six components do not all visually appear to fit the data adequately (Fig. 5). Differentiating between age cohorts becomes more difficult with increasing age class because the growth increment decreases whereas the variation increases. Ageing *M. asterias* is more difficult after maturation. Maturity for males and females is estimated at 78 cm L_T and 4–5 years and 87 cm L_T and 6 years, respectively (Farrell *et al.*, 2010*b*). In the length–frequency chart (Fig. 5), each component could be attributed to an age group. Component five seems to be a wide distribution with overlap in the age classes, and

FIG. 8. Photographic examples of biofouling: (a) number 0267, the dorsal fin has grown around the rear end of the tag, (b) number 0284 was marked on 31 July 2011, recaptured on 9 August 2012, 375 days later by CEFAS during the English Q3 IBTS survey, at about the same location in the Dutch Delta where it initially was tagged. The Rototag was grown over with a string of mussels of *c.* 8 cm. This male *Mustelus asterias* had nevertheless grown from 71 to 80 cm L_T. Both *M. asterias* and tag were found in the net, the wear and tear of the net must have torn the tag loose, (c) number 2132 and (d) number 2984, in both cases the dorsal fin has grown over the tag at the front end and some biofouling has occurred.

incorporates juvenile, maturing and mature specimens. There are many ages mixed in here that were difficult to separate with the method used and the data that were available.

The increase in mass of females over 80 cm [Fig. 6(b)] is indicative of maturity (Farrell *et al.*, 2010*b*). The slight deviation in the mass-to-length relationships between this study and Farrell *et al.* (2010*a*) is probably due to the smaller number of large >80 cm L_T specimens in this study [Figs 5 and 6(a)].

INCREASED ABUNDANCE OF *M. ASTERIAS* IN THE DUTCH DELTA

In previous decades, *M. asterias* was reported to be rare in Dutch coastal waters (Nijssen & de Groot, 1987). The current tagging group, with considerable experience in the study area over a five decade period, rarely caught this species before 2009. In addition, ICES assessments also show an increase in *M. asterias* abundance in recent years, in both survey catches (ICES, 2014) and in commercial and recreational fisheries (McCully Phillips & Ellis, 2015). This increase may be another example of an already widely observed change in fish assemblage and latitudinal responses in the North Sea caused by the effects of climate change such as a decrease in pH, eutrophication and warming waters (Rogers & Ellis, 2000; Reid *et al.*, 2001; Beaugrand, 2004; Perry *et al.*, 2005; Weijerman *et al.*, 2005; Dulvy *et al.*, 2008). *Mustelus asterias* is a ground shark and specialist feeder on crustaceans (Ebert *et al.*, 2013) and as such has a narrow dietary and habitat niche and consequently is sensitive to environmental fluctuations (Munroe *et al.*, 2014). Water temperature is one of the main predictors of elasmobranch occurrence (Martin *et al.*, 2012; Schlaff *et al.*, 2014) and data from this study show that catches in the Dutch Delta were nearly zero when the water temperature fell below 13° C (Fig. 2). This should be further studied.

Monitoring the overall development of the population would also be helpful to management. Although the species is listed by the IUCN as of Least Concern (Gibson *et al.*, 2008; Serena *et al.*, 2009), it is also concluded by ICES that some precaution is required. The *M. asterias* population in the Mediterranean Sea was observed to decrease by 85% between 1994 and 2006 due to over fishing (Renon *et al.*, 2001; Serena *et al.*, 2009). The north-east Atlantic population also faces significant fishing pressure (ICES, 2014), but the effect on population level is difficult to assess. McCully Phillips & Ellis (2015) suggest that more *M. asterias* are caught commercially because exploitation shifted due to the lack of *S. acanthias*. No accurate estimates of catch are available as many nations report an unknown proportion of landings in aggregated landings categories (ICES, 2014) including 'hounds NEI' (not elsewhere identified) or as 'dogfish NEI' (Farrell *et al.*, 2010*a*). Therefore, obligatory identification in landings of 'hounds' and 'dogfish' to the species level is recommended. As *M. mustelus* does not occur in the English Channel and the southern North Sea (Farrell, 2010), this species can be ruled out from landing reports. In addition, the difference between *G. galeus* and *M. asterias* can be made quite simply based upon their short and long second dorsal fin, respectively.

TAG-RECAPTURE PROGRAMME CRITICALLY REVIEWED

The tagging team and methodology used in this study have remained constant during the study period. The dataset collected gives a good representation of annual and seasonal captures since the team fishes throughout the year, at specific locations, always using the same gear and bait. The anglers collected enough data to estimate the seasonal changes in distribution (*e.g.* duration and first and last occurrences) of immature and mature elasmobranchs and pups in the Dutch Delta. The capture results indicate that the angling practice (with small, strong and very sharp hooks) currently used has a good probability of catching all sizes, including pups of *M. asterias*. Therefore, angling for this species has an advantage over commercial gear (with restrictions on mesh size) in collecting data on all length classes and keeping specimens alive. The 3·6% tag-return-rate (Table II) for the period 2011–2014 falls within the range reported by Kohler & Turner (2001). In 191 shark tag-recapture studies using conventional tags, more than half reported return rates of <5% (Kohler & Turner, 2001). This rate can change during an ongoing tagging programme which partially depends upon willingness to report. The yellow rototags stand out in the catch and photographic evidence shows that the printed text is still clearly readable after 3 years at sea. Half of the recaptures were delivered to fisheries institutes such as IMARES or IFREMER, which highlights their key role in collecting recapture data.

As *M. asterias* under 40 cm L_T were untagged, no recapture information was collected for this group. To collect more data on juveniles, tagging could be improved by using different types of tags more suited to their delicate dorsal fins. The rototags used in this study have been applied in numerous elasmobranch tagging studies worldwide (Stevens, 2000; Kohler & Turner, 2001; Rechisky & Wetherbee, 2003). There are some known issues of possible sessile biofouling and hydrodynamic drag (Latour, 2005; Dicken *et al.*, 2011); nevertheless, the use of rototags is generally accepted as an efficient way of marking with minimal damage to the shark (Heupel *et al.*, 1998; Kohler & Turner, 2001). Photographic evidence of 10 recaptured individuals showed sessile biofouling in the form of mussel-strings, which can cause drag on the tag and can negatively influence wound healing, growth and welfare of the animal (Latour, 2005; Dicken *et al.*, 2011). In several cases, the dorsal fin had grown over the tag resulting in poor wound healing, indicating that the tags had been fitted too tightly. Therefore, this information will be used to update the field protocol for future seasons.

ANGLER-LED TAGGING PROGRAMMES AND IMPLICATIONS FOR MANAGEMENT AND CONSERVATION OF ELASMOBRANCHS

An important objective of the EU action plan on sharks is to 'deepen knowledge both on shark fisheries and on shark species and their role in the ecosystem'. The results of the angler-led tagging programme for *M. asterias* as presented here clearly contribute to this, *e.g.* the observations of seasonal occurrence and importance of different areas ranging from the southern North Sea to the Bay of Biscay, and indications for a separate population using the southern North Sea. This knowledge can be used to develop more direct and effective management measures.

A second objective of the EU action plan on sharks is to 'ensure that directed fisheries for shark are sustainable and that their by-catches are properly regulated'. Close cooperation with anglers within this tagging programme resulted in progress towards making the directed fisheries on sharks more sustainable by optimizing survival due to better handling procedures. During this study, bookings for shark-trips increased and the working relationship between charter boat skippers, paying-passengers, the Royal Dutch Angling Association and IMARES was strengthened over the course of the tagging programme. Skippers and anglers learned how to properly handle *M. asterias*, which resulted in all the tagged specimens being released alive. The presentation of the results of the tagging programme (Sharkatag) received national media attention, and this created more public awareness, which in turn can help the conservation of elasmobranchs in the southern North Sea.

Anglers are widely represented in society and are important stakeholders in elasmobranch conservation and exploitation management. Sport-fishing is a popular form of outdoor recreation (Ditton *et al.*, 2002) and world-wide angling enterprises that depend on elasmobranch fisheries have increased (Gallagher & Hammerschlag, 2011; Shiffman & Hammerschlag, 2014). Anglers appreciate elasmobranchs for their recreational non-consumptive value and, provided low mortality can be assured with best catch-and-release angling practice (Bartholomew & Bohnsack, 2005; Cooke & Suski, 2005; Cooke *et al.*, 2013), certain species such as *M. asterias* can be considered a valuable asset to charter boat skippers and their paying-passengers.

The commercial value of the species supports sea angling charters in the Netherlands. In contrast, within commercial fisheries, *M. asterias* is a very low value species.

Mustelus asterias clearly has a significantly higher value alive (to anglers, practising catch-and-release) than dead (to commercial fishers) in the Netherlands. This also partly explains the higher 30% release rate of the shark by Dutch commercial fishers in contrast to fishers from other countries where only 7% is released.

It would, therefore, be useful to fisheries managers, when developing and deploying management plans where economic and ecological interests are being represented, to assess the non-consumptive value of elasmobranch stocks for recreational purposes and ecotourism conservation, in comparison to the traditional consumptive value of the harvest of their fins and flesh.

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