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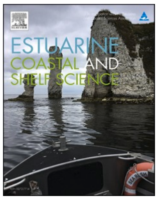

Vertebral elemental composition reveals ontogenetic changes in habitat use in a Northeast Atlantic mesopredator shark

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ABSTRACT

Sharks are increasingly threatened with extinction due to overexploitation. Research priorities to mitigate these trends include identifying ontogenetic variations in spatial and temporal habitat use, as well as critical habitat areas to protect key life stages and processes. Here we demonstrate the regional applicability of laser ablation inductively coupled plasma mass spectrometry with natural tags (barium, magnesium, manganese, strontium) for investigating broad-scale habitat use patterns amongst at risk elasmobranchs in the Northeast Atlantic. We assess vertebral elemental composition in smallspotted catsharks *Scyliorhinus canicula* as a model species in the Bristol Channel and English Channel, UK, and identify ontogenetic variations throughout the sampling area, with shared habitat use by young-of-year and sub-adults distinct from adult life stages. We find sex segregation only amongst adults, which appears to be driven by male dispersal. Finally, we suggest that distinct adult populations appear to use multiple birthing grounds which therefore are potentially critical habitats for population recruitment, but with differential importance according to usage. Together these findings present an opportunity to integrate precautionary management into current conservation planning in the UK; *S. canicula* is centrally important to marine food webs, therefore strengthening population robustness against emerging fisheries and environmental perturbations should be a key objective.

1. Introduction

Global marine biodiversity declines threaten to undermine marine ecosystem function, likely with far-reaching and severe consequences. Conservation management should prioritise key species and critical habitats for protection (Duarte et al., 2020), mitigation of anthropogenic impacts on natural systems, and promotion of a planetary health approach to human consumptive behaviours. Sharks boast ecological (Heithaus et al., 2008) and economic (Clua et al., 2011; Gallagher and Hammerschlag, 2011; Huveneers et al., 2017; Vianna et al., 2012) importance, but are overexploited (MacNeil et al., 2020; Pacoureau et al., 2021; Simpfendorfer et al., 2023) and increasingly threatened with extinction (Dulvy et al., 2014, 2021). Sharks are a conservation priority; mortality, however, continues to rise in national waters despite decades of management attention (Worm et al., 2024), perpetuating widespread long-term decline (Dedman et al., 2024). Safeguarding species traits and ecological functionality should be key conservation objectives (Coulon et al., 2024; Dedman et al., 2024), particularly to support ecosystem resilience under future change scenarios. This compounds the challenge of strengthening shark management – a substantial proportion of threatened Northeast Atlantic marine fish species are functionally distinct (Coulon et al., 2023). Knowledge gaps including population status and movement ecology (Jorgensen et al., 2022) must be addressed to achieve management success. This is particularly true for small-bodied sharks (Dedman et al., 2024) and species that do not typically attract research interest (Simpfendorfer et al., 2011).

Laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) enables the use of vertebral elemental signatures as natural tags to extrapolate habitat use, movement and population structure insights in fish (Coiraton et al., 2020; Feitosa et al., 2020, 2021; LaFreniere et al., 2023; Livernois et al., 2021; Mohan et al., 2018; Pistevos et al., 2019; Smith et al., 2016; TinHan et al., 2020). Natural tags reliably reflect environmental conditions and include barium, magnesium, manganese, strontium, and zinc (McMillan et al., 2017). Specifically, the relative

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vertebral composition of strontium and barium are proxies for environmental salinity, with high concentrations indicating marine and freshwater use, respectively (Grant et al., 2023; TinHan et al., 2020), while environmental temperature is reflected in magnesium (negatively) and manganese (positively) composition (Smith et al., 2013). Unlike acoustic tagging and telemetry, LA-ICP-MS natural tag analysis is not space-limited by acoustic array coverage. This approach can therefore yield broad-scale insights into elasmobranch ecology, such as seasonal migration (Coiraton et al., 2020; Smith et al., 2016) and nursery habitat use (Feitosa et al., 2020; McMillan et al., 2018; TinHan et al., 2020). Thus, opportunistic fisheries sampling can be exploited to address knowledge gaps (Coiraton et al., 2020; Feitosa et al., 2020; Livernois et al., 2021). This method has not, however, been commonly applied to elasmobranchs in the Northeast Atlantic or Mediterranean regions.

The smallspotted catshark *Scyliorhinus canicula* (L. 1758) is the most widely distributed nearshore shark species in Northeast Atlantic shelf (Ellis and Shackley, 1997) and Mediterranean seas (Follesa et al., 2019), and hence a suitable model species for regional LA-ICP-MS studies. It has historically been assessed as overexploited in Europe (Osio and Cardinale, 2013), heavily fished throughout the Iberian Peninsula (Rodríguez-Cabello et al., 2005), and remains prominent in Portuguese fisheries landings (Alves et al., 2020; Marques et al., 2021). Wider ramifications of *S. canicula* population decline, given trophic centrality in regional food webs (Wieczorek et al., 2018), warrant conservation and management attention. Common shark conservation management actions include implementing marine protected areas (MPAs) or shark sanctuaries (Chapman et al., 2013, 2021; Worm et al., 2013), and protection benefits emanating from this approach have been documented for *S. canicula* (López et al., 2025; Papadopoulo et al., 2023; Rodríguez-Cabello et al., 2008). Notably, however, population biology has historically been a species knowledge gap (Moore, 2001), which can limit MPA design effectiveness. Long-term population genetic stability in the Western English Channel belies low dispersal capacity and thus may reflect population reduction, expansion and high gene flow in the Northeast Atlantic (Gubili et al., 2014). Historical mercury concentrations also suggest distinct adults populations in the Irish Sea (Leah et al., 1991), although single element inherently yields lower resolution insights than multi-element analysis.

Lifetime LA-ICP-MS analysis can potentially elucidate species evidence gaps regarding ontogenetic habitat use, yield broad-scale insights into sexual, ontogenetic, and regional population structure, and thus inform and strengthen conservation and fisheries management. Current biodiversity targets in the UK are an opportunity to incorporate species-level evidence into updated objectives for *S. canicula* management, and thereby encourage similar action throughout its distribution. As such, we hypothesise that adult *S. canicula* populations are regionally spatially distinct, sexually segregated, and connected by birthing grounds that are essential habitats. To test this hypothesis, we assessed *S. canicula* vertebral elemental composition across south and west Wales, and south Devon for (1) spatial variations; (2) ontogenetic variations; and (3) evidence of critical habitats.

2. Materials and methods

2.1. Sampling protocol

A total of 49 *S. canicula* were used in this study (Table S1). Sampling was conducted during 2021 and 2022 at seven sites, with five on the south coast of Wales (three sampled in 2021, two in 2022) and two on the south coast of England (one sampled in 2021 and one in 2022), thereby ensuring comprehensive representation throughout the region (Fig. 1). The Bristol Channel is a highly dynamic tidal environment between Wales and England. There are major human population centres in Bristol, Cardiff, and Swansea, and several Special Areas of Conservation (SAC), Special Protection Areas (SPA) and Ramsar sites (Fig. 1). *S. canicula* at all sites except Barry were recreational angling bycatch, fresh frozen. At the Barry site, dead samples were obtained several

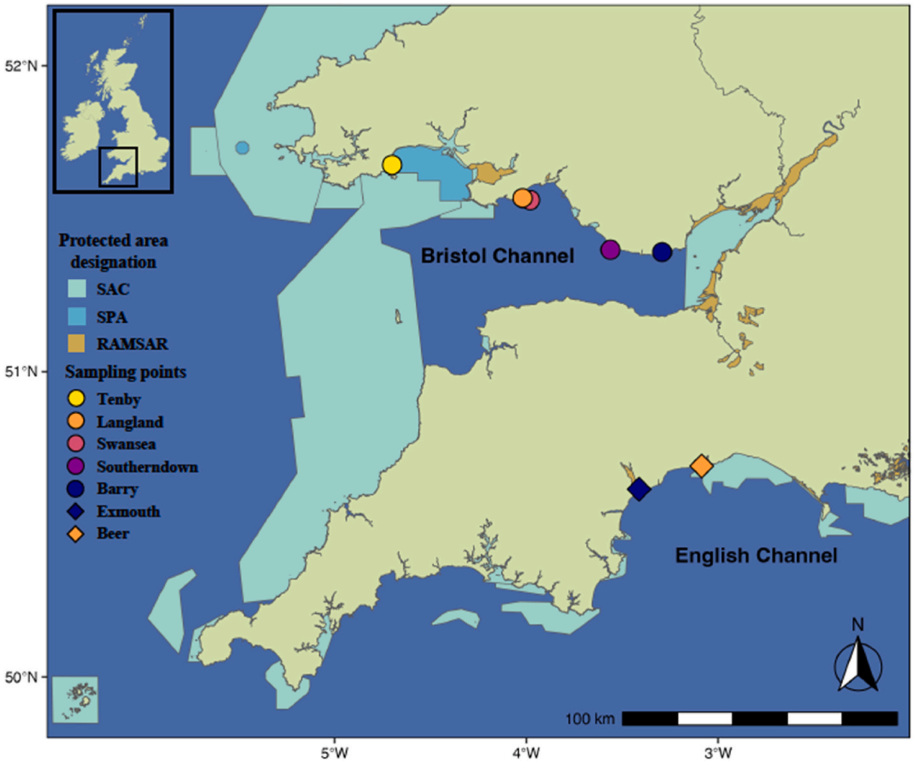

Fig. 1. Study sampling locations for smallspotted catsharks *Scyliorhinus canicula* (L. 1758), Special Areas of Conservation (SAC), Special Protection Areas (SPA) and Ramsar sites in the Bristol Channel and English Channel, UK.

metres above the high tide line which, together with the presence of hooks in several, suggests angling discard. This is common practice with *S. canicula* landed by anglers in that location. Precise date of landing was unknown for these specimens; some were highly desiccated but there was no evidence of scavenging, which suggests recent death.

2.2. Sample preparation

Individuals were first stored at −20 °C and later thawed for 24 h in a laminar flow hood. Once thawed, the following standard body metrics were recorded: total length, fork length, body condition when collected (fresh, n = 41; desiccated, n = 8), and sex. It was not possible to accurately measure total length for the desiccated specimens. Therefore, we first used fresh frozen samples to validate historical findings that vertebral length is proportional to total length in *S. canicula* (see Ivory et al., 2004), then estimated total length from vertebral length measurements for desiccated specimens. Age estimates were extrapolated for each specimen using sex-specific Von Bertalanffy Growth Function parameters for *S. canicula* (Table S2) and the following equation, where a is age, k is the growth coefficient, t_0 is the theoretical age when size is zero, and L_∞ is asymptotic size:

$$L(a) = L_\infty(1 - \exp(-k(a - t_0)))$$

A minimum of three post-cephalic vertebrae were removed from each individual and air dried for 24 h in a laminar flow hood. The neural arch and extraneous tissue were removed with a scalpel and vertebrae were placed in 5 % bleach for 5 min to remove any remaining tissue, then washed in Milli-Q water (Mohan et al., 2017; Tillett et al., 2011). Vertebrae were manually cleaned, dried again in a laminar flow hood, then stored at −20 °C, following length measurement to the nearest 0.5 mm. Prior to mass spectrometry analysis, vertebrae were thawed then embedded in Araldite (2020) resin (Fig. 2a), ground longitudinally from one side with a diamond grinding wheel and smoothed with 1200 grit silicon carbide paper, then mounted on a glass slide with Araldite 2020 resin. Next, the exposed side was cut to a 1 mm ‘bowtie’ section using a diamond saw, then ground to 300 μm with 800 and 1200 grit silicon carbide papers. Finally, this was polished using a 0.3 μm aluminium oxide slurry and washed in an ultrasonic bath (Fig. 2b).

2.3. Laser ablation inductively coupled plasma mass spectrometry protocols

LA-ICP-MS analyses were undertaken using an ASI RESOlution 193 nm Excimer laser coupled to an Agilent-8900 triple quadrupole ICP-MS, with transects manually set along the corpus calcareum (Fig. 2c). For each specimen, a single transect was run on each of three vertebrae to yield three replicates. Transects were ablated from the centre to the tips of the vertebrae, approximately parallel to major growth axes to incorporate chronological elemental signatures throughout specimen lifetime. Thus, transect start and end represent embryonic and time of death elemental signatures, respectively. LA-ICP-MS settings were manually adjusted to optimise signal stability and sensitivity (Samperiz, 2022) in bioapatite matrix samples (such as shark vertebrae). Laser settings were as follows: shot frequency 15 Hz, fluence 3 J cm^{-2}, scan speed 10 μm s^{-1}, and ablation spot size 100 μm. Helium flow and Nitrogen flow were 350 mL min^{-1} and 3.5 mL min^{-1}, respectively, and National Institute of Standards and Technology (NIST) 612 and NIST 614 glass standards were ablated periodically between transects. The ICP-MS used nickel cones and radio frequency power of approximately 1230 W, nebuliser gas flow rate of 0.8 l min^{-1}, with a time resolved acquisition mode and time slice of 1.10 s.

2.4. Data processing and statistical analysis

Raw data were first corrected for background ratios and instrument drift, outliers (3 SD) removed, and then converted to standardised element:calcium molar ratios in Python using the LAtools package (Branson et al., 2019). The three replicates per individual were visually aligned in QAnalySeries (Kotov and Pälike, 2018) using strongly cyclical Mn:Ca peaks (Figs. S2–8), which were additionally used to verify estimated age given the association between manganese incorporation and seasonal temperature fluctuations (Elsdon and Gillanders, 2006; Smith et al., 2013). Finally, molar ratios were converted to concentration (ppm) using ^{43}Ca as the internal standard and with a 35 wt % for hydroxyapatite (McMillan et al., 2017; Mohan et al., 2018).

Investigating ontogenetic variation in concentration levels required assigning different portions of the vertebrae to the following life stages: pre-natal, young-of-year (to 1 year; YOY), sub-adult (1 year–50 % maturity), and adult. *Scyliorhinus canicula* in the Bristol Channel (sex ratios 1.2♀: 1♂) hatch at approximately 100 mm, with 50 % maturity reached at 550 mm and 520 mm total length for females and males, respectively (Ellis and Shackley, 1997). Despite regional variation in these characteristics (Capapé et al., 2014; Kousteni et al., 2010), parameters obtained from elsewhere in the UK are comparable (Henderson and Casey, 2001). Therefore we used estimated age at 50 % maturity, together with annual Mn:Ca peaks, to assign a position on the vertebral transect corresponding to each life stage (Figs. S2–8) and extract the median values (Feitosa et al., 2021; LaFreniere et al., 2023). This yielded single values per life stage for all individuals sampled, which were used in all subsequent analyses.

Data were analysed using R software (v4.2.2; R Core Team, 2022), with the ‘emmeans’ (Lenth, 2024), ‘MASS’ (Venables and Ripley, 2002), ‘performance’ (Lüdecke et al., 2021), ‘TropFishR’ (Mildenberger et al., 2017), and ‘vegan’ (Oksanen et al., 2022) packages. We first used a set of generalised linear models to investigate the association between sampling site (spatial predictor variable), sex, life stage, and their interaction (biological predictor variables), and each single element vertebral composition (response variables). We tested error family and link function combinations based on non-normal distributions of zero-bounded continuous data, used the ‘performance’ package to check model assumptions, and selected for the lowest AIC value (Akaike’s information criteria, AIC; Akaike, 1998) and smallest residuals. We then

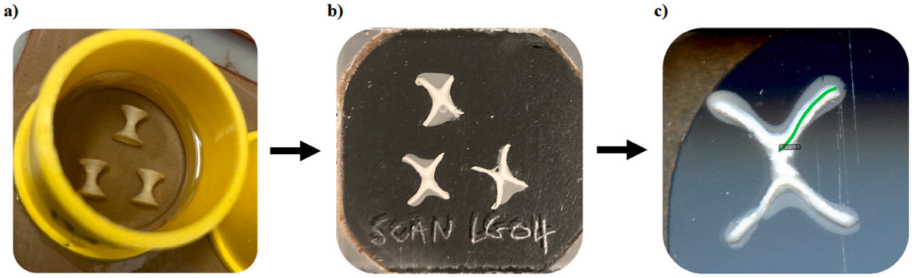

Fig. 2. Preparation steps for smallspotted catshark *Scyliorhinus canicula* (L. 1758) vertebrae isolated from the vertebral column, following cleaning and removal of connective tissue: a) embedded in resin; b) ground and polished, and; c) laser transect assigned along vertebral growth axis to incorporate chronological elemental signatures throughout specimen lifetime.

used Tukey *post-hoc* pairwise tests in the ‘emmeans’ package to assess both ontogenetic and sex-based differences in elemental composition. Last, we used cluster analysis to investigate spatial population structure, both for young-of-year and adult life stages. Linkage method was selected according to agglomerative coefficient, with the Ward linkage method higher for both young-of-year (0.91) and adults (0.89) than any of the average, single or complete linkage methods. Average silhouette width was then used to identify the optimum number of clusters for each life stage as a proxy for sub-populations.

3. Results

Scyliorhinus canicula used in this study comprised 25 females and 24 males (1♀: 0.96♂ sex ratio). All seven sites along the Bristol and English Channels yielded all life stages, except Swansea with no adults. Mean total length ranged between 456 mm and 590 mm at the Barry and Beer sites respectively, equating to a mean age range of 5.3–9 years (Table S1).

Adult life stages had a significant influence on all target elements (barium, $t = 2.73$, $p < 0.01$; strontium, $t = 8.15$, $p < 0.001$; magnesium, $t = 3.04$, $p < 0.01$; manganese, $t = 3.42$, $p < 0.001$; Fig. 3; Table S3). Life stage overall explained the most deviance for strontium, magnesium and manganese (45.95 %, 20 %, 21.69 %, respectively, Table 1), and the second most deviance for barium (11.11 %, Table 1). This was confirmed by Tukey *post-hoc* tests (Table S4), with barium lower in both young-of-year ($z = -2.98$, $p < 0.01$) and sub-adults ($z = -3.63$, $p < 0.001$) than adults, strontium higher ($z = -10.67$, $p < 0.001$; $z = -6.76$, $p < 0.001$; respectively), manganese lower ($z = -4.02$, $p < 0.001$; $z = -5.31$, $p <$

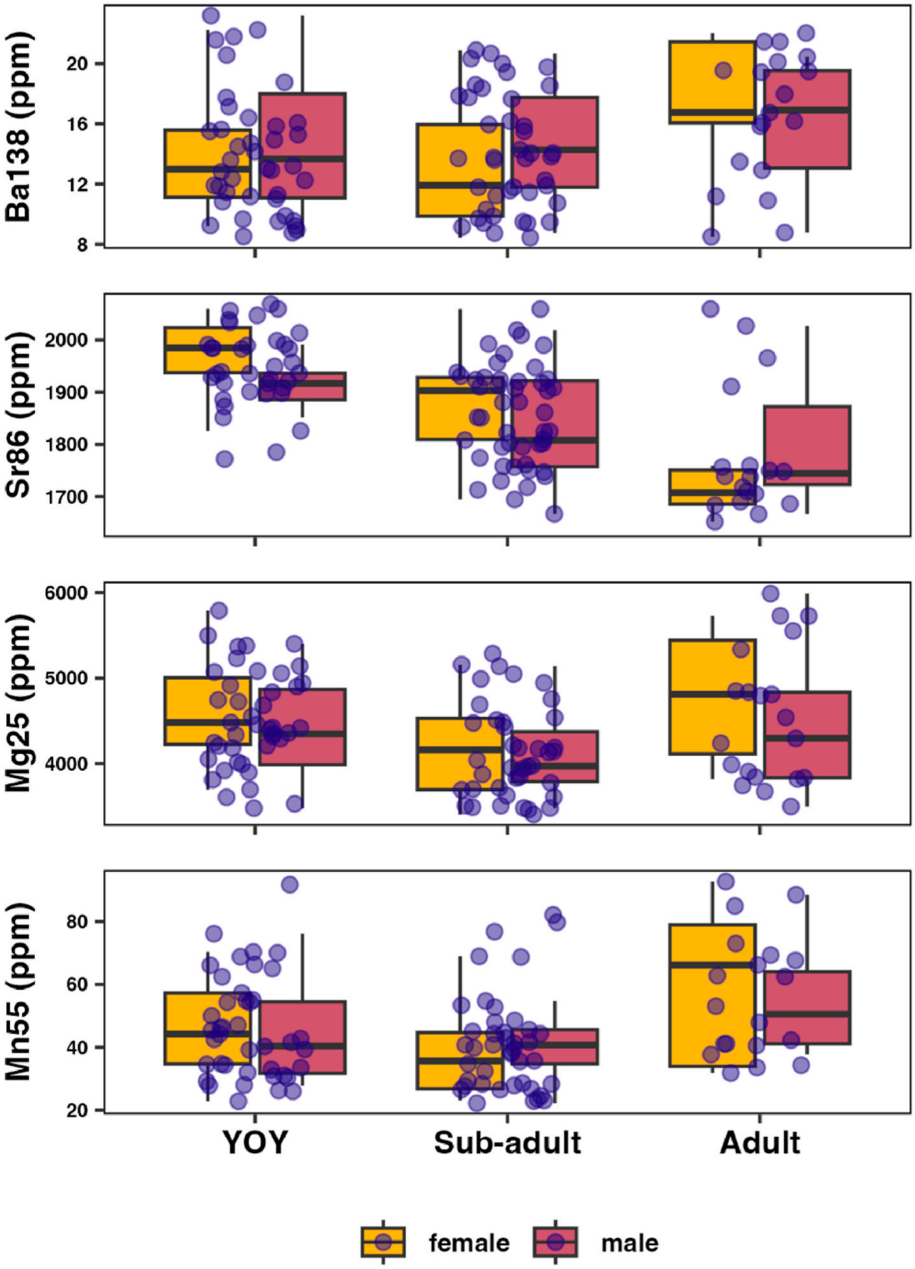

Fig. 3. Ontogenetic sex-based variation in smallspotted catshark *Scyliorhinus canicula* (L. 1758*)* vertebral elemental composition across sampling sites in the Bristol Channel and English Channel, UK (median values per life stage per individual). Top to bottom: barium, strontium, magnesium, and manganese. YOY = young-of-year. Boxes represent interquartile range, horizontal line represents median, whisker length = 1.5 * interquartile range (outliers removed). Note different y axis scales.

Table 1
Analysis of deviance table for generalised linear models used to investigate the association between site, sex and life stage, and single element response variables (barium, magnesium, manganese and strontium) within the vertebral composition of smallspotted catsharks *Scyliorhinus canicula* (L. 1758) in the Bristol Channel and English Channel, UK.

	Df	Deviance	Resid. Df	Resid. Dev	Pr(>Chi)	% deviance explained
Response: Barium (^{138}Ba)		***Family = Inverse gaussian***			***Link = log***	
NULL			127	2.16		
Site	6	0.67	121	1.49	$<$0.001	31.02
Sex	1	0.07	120	1.42	$<$0.05	3.24
Life_stage	2	0.24	118	1.18	$<$0.001	11.11
Sex:Life_stage	2	0.08	116	1.1	0.06	3.70
Response: Strontium (^{86}Sr)		***Family = Gamma***			***Link = inverse***	
NULL			127	1.11		
Site	6	0.08	121	1.03	$<$0.01	7.21
Sex	1	0.01	120	1.02	0.15	0.90
Life_stage	2	0.51	118	0.51	$<$0.001	45.95
Sex:Life_stage	2	0.01	116	0.5	0.32	0.90
Response: Magnesium (^{25}Mg)		***Family = Inverse gaussian***			***Link = identity***	
NULL			127	0.002		
Site	6	0.0002	121	0.002	$<$0.01	10
Sex	1	0.00004	120	0.002	$<$0.05	2
Life_stage	2	0.0004	118	0.001	$<$0.001	20
Sex:Life_stage	2	0.0001	116	0.001	$<$0.01	5
Response: Manganese (^{55}Mn)		***Family = Inverse gaussian***			***Link = log***	
NULL			127	0.83		
Site	6	0.09	121	0.74	$<$0.01	10.84
Sex	1	0.001	120	0.73	0.7	0.12
Life_stage	2	0.18	118	0.56	$<$0.001	21.69
Sex:Life_stage	2	0.02	116	0.54	0.19	2.41

0.001; respectively), and magnesium lower in sub-adults than adults ($z = -5.72$, $p < 0.001$). Site explained the most deviance for barium (31.02 %, Table 1), and the second most deviance for strontium, magnesium and manganese (7.21 %, 10 %, 10.84 %, respectively, Table 1). Sex influenced only barium ($t = -2.59$, $p < 0.05$; Table S3) while the interaction between sex and adult life stages influenced magnesium ($t = -2.77$, $p < 0.01$; Table S3), reflected in significant differences in Tukey *post-hoc* tests (Table S5) between sexes (barium, $z = 3.28$, $p < 0.01$; magnesium, $z = 3.32$, $p < 0.001$). This further suggests that adult males are the primary driver of the extrapolated dispersal patterns.

Multi-element non-metric multidimensional scaling revealed tight clustering and little sexual segregation amongst young-of-year and sub-adults, but increasingly pronounced dispersal and possible sex segregation within adult life stages (Fig. 4). Cluster analysis of multi-element

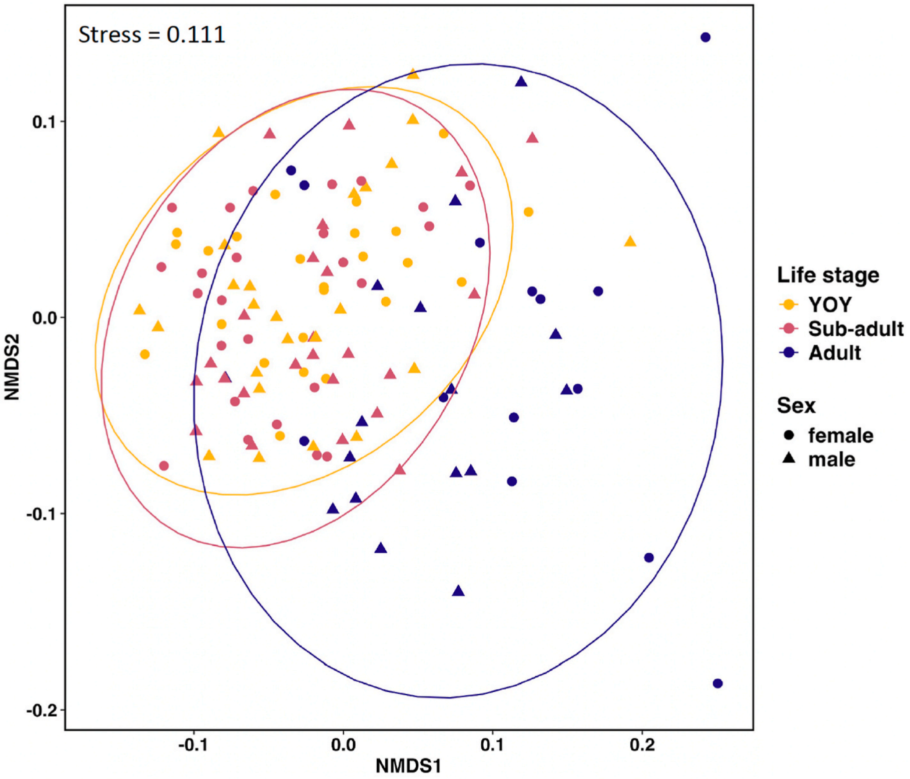

Fig. 4. Multi-element (barium, magnesium, manganese, strontium) non-metric multidimensional scaling plot of smallspotted catshark *Scyliorhinus canicula* (L. 1758) vertebral composition in the Bristol Channel and English Channel, UK (median elemental concentration values per life stage per individual).

vertebral composition yielded three population clusters for young-of-year and two population clusters for adults, using the average silhouette width method to determine optimum number of clusters; one young-of-year cluster comprised only a single individual, while one adult cluster comprised two individuals (Fig. 5).

4. Discussion

Here we apply LA-ICP-MS with natural tags to investigate spatial and ontogenetic population structure in *S. canicula*, a suitable model species for Northeast Atlantic and Mediterranean elasmobranch population studies given its abundance and widespread distribution. This addresses knowledge gaps regarding applicability of LA-ICP-MS both for regional studies, and for transferability amongst different target elasmobranch species (Pistevos et al., 2019).

Our results indicate pronounced ontogenetic spatial segregation and suggest possible adult sexual segregation in *S. canicula* in the Bristol Channel and English Channel, UK. Young-of-year and sub-adults show little sexual segregation in shared offshore or deeper habitat areas post-hatching. Aggregation behaviour with no sexual segregation in neonate and juvenile *S. canicula* may reflect social preferences and familiarity, as well as habitat preference and predation risk reduction (Jacoby et al., 2012). Ontogenetic elemental trends (lower strontium and magnesium but stable or higher barium and manganese) then suggest dispersal and range expansion to nearshore shallow areas with increasing maturity, culminating in possible sexual segregation amongst adults that has also been documented in *S. canicula* elsewhere (Papadopoulo et al., 2023; Sims et al., 2001; Wearmouth et al., 2012). It is unclear what drives this behavioural transition and when, but it may be related to male-biased dispersal (Gubili et al., 2014; Rodríguez-Cabello et al., 2007), differential sex-based foraging habits (Kimber et al., 2009), or female avoidance of males (Micarelli et al., 2020; Wearmouth et al., 2012). Insights in line with current knowledge not only support regional application of LA-ICP-MS but also present an opportunity for standardised protocols and comparable studies. Finally, we use multi-element dissimilarity cluster analysis to explore the existence of population clusters for each life stage, with one cluster substantially bigger amongst adults. The different cluster sizes indicate possible multiple birthing grounds with differential importance for regional adult stock recruitment, adding to the ecological evidence base for this species.

Central trophic importance in regional marine food webs suggests *S. canicula* depletion would have ecosystem-wide ramifications (Wieczorek et al., 2018). This alone justifies management attention, particularly in the context of functional shifts in regional elasmobranch assemblages (Coulon et al., 2024) and projected climate pressures (Pegado et al., 2020; Ripley et al., 2021). Furthermore, long-term increases in UK abundance (McHugh et al., 2011) may simply reflect a lack of targeted fishing, since overfishing can deplete shark populations (Dulvy et al., 2021; Worm et al., 2024) including *S. canicula* (Barausse et al., 2014). Future fisheries pressure could yet arise, and *S. canicula* is vulnerable both to this and to human coastal impacts (Navarro et al., 2016). Sustainably managed shark fisheries, however, are rare (Simpfendorfer and Dulvy, 2017), although protection and management success typically associated with strong governance and highly protected areas in wealthy nations (Simpfendorfer et al., 2023) suggests that *S. canicula* in the UK may represent such an opportunity.

Marine protected areas can yield recovery in exploited *S. canicula* populations (Rodríguez-Cabello et al., 2008), even conferring indirect benefits when not specifically designed to protect sharks but incorporating egg nursery habitats (López et al., 2025). To increase success, however, MPAs designed to protect sharks should consider all life stages (Kinney and Simpfendorfer, 2009). In simultaneously sampling several age classes we show not only that young-of-year remain in post-hatching habitats for extended periods, but also that mixing of immature life stages is repeated across years. These are two of three criteria for the classification of shark nurseries (Heupel et al., 2007). Nursery grounds

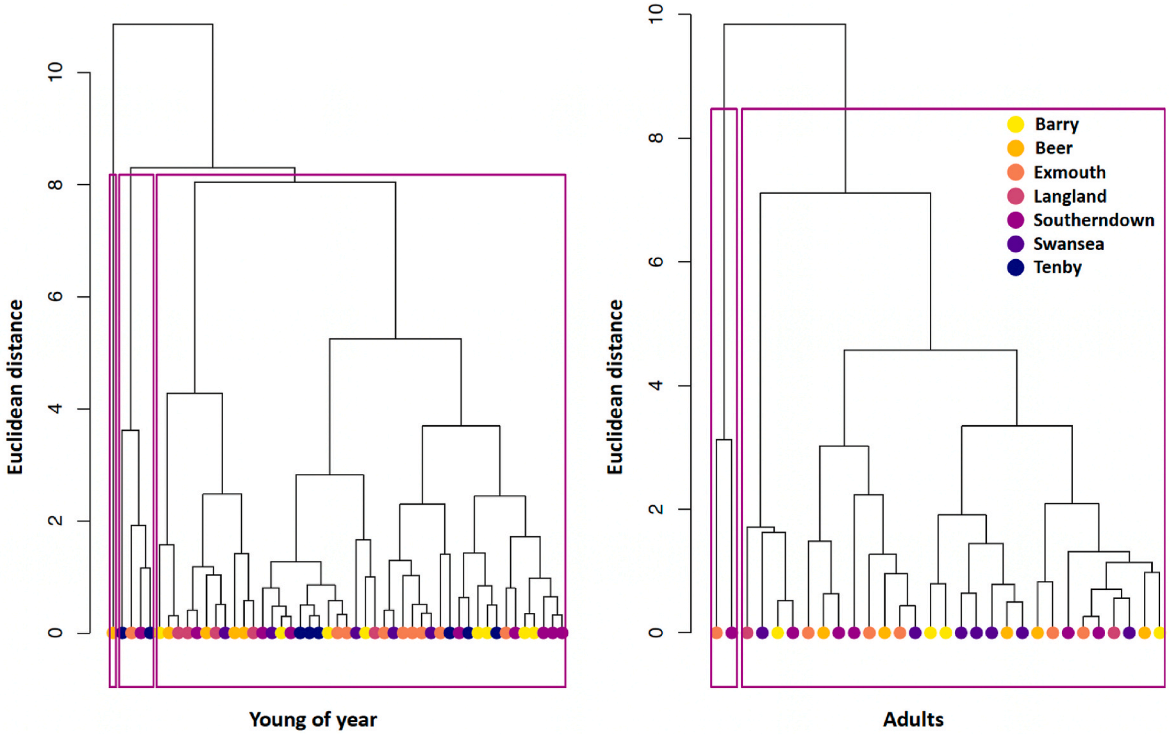

Fig. 5. Cluster analysis for multi-element (barium, magnesium, manganese, strontium) vertebral composition in young-of-year (left; three clusters) and adult (right; two clusters) smallspotted catsharks *Scyliorhinus canicula* (L. 1758) in the Bristol Channel and English Channel, UK (median elemental concentration values per life stage per individual). Each node represents an individual, with colour according to sampling site. Note: fewer adult nodes reflects immature individuals that were sampled. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

are important for oviparous species given high early life stage mortality (Ripley et al., 2021), and egg case nurseries have been identified for *S. canicula* in the Mediterranean associated with both favourable habitats (Cau et al., 2013, 2017) and environmental conditions (López et al., 2025). Together with migration corridors (Papadopoulo et al., 2023), such habitats can be critical for *S. canicula*, particularly given potentially differential importance for regional populations. Further work investigating this in UK waters should be prioritised, given shark nursery research bias towards tropical coastal species (Heupel et al., 2018). This should target egg-laying habitats such as the pink sea fan *Eunicella verrucosa* (Hiscock et al., 2019), and citizen science egg case sightings records that may reflect birthing ground distribution. These data could inform telemetry studies to elucidate precise critical habitat locations, since archival depth telemetry can reveal putative egg-laying behaviour in *S. canicula* (Wearmouth et al., 2013). Adults typically make periodic returns to deposit egg cases (Wearmouth et al., 2013), but this may not be sufficiently protracted to be reflected in vertebral microchemistry and hence not detected in our study. Yet, higher female philopatry (Gubili et al., 2014) and shared pre-adult habitat use illustrate potential sex- and age-biased vulnerability to localised fishing pressure, with implications for adult recruitment. Suitably located MPAs that restrict fishing, activities that threaten habitat stability, or both, are a management approach that could be implemented throughout the wider *S. canicula* distribution.

4.1. Conclusion and recommendations

The findings presented here do not allow definitive identification of critical habitats, but nevertheless suggest novel regional *S. canicula* ecology insights that shared habitats strengthen connectivity between widely dispersed adults. This is relevant for the Welsh Marine Evidence Strategy (2019–2025) to incorporate species action plans for *S. canicula* as an important predator in regional coastal seas. Future work to test this hypothesis should include LA-ICP-MS analysis with contiguous sampling at higher spatial resolution, together with telemetry studies. Identifying such areas is needed to integrate sharks into existing conservation infrastructure, and this study demonstrates regional applicability for LA-ICP-MS to elucidate habitat use patterns amongst at risk elasmobranchs in the Northeast Atlantic.

CRediT authorship contribution statement

Neil D. Cook: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Ana Samperiz:** Writing – review & editing, Methodology, Investigation, Data curation. **Morten Andersen:** Resources, Methodology. **Edward Inglis:** Resources, Methodology. **Marc-Alban Millet:** Writing – review & editing, Supervision, Resources, Methodology, Investigation, Data curation, Conceptualization. **Jo Cable:** Writing – review & editing, Supervision, Conceptualization. **Sarah E. Perkins:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecss.2025.109255.

Data availability

Data will be made available on request.

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