Marine Ecology

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RESEARCH ARTICLE

An Assessment of Demersal Elasmobranch Occurrence and Associated Habitats Using an Autonomous Underwater Vehicle (AUV)

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Received: 22 February 2024 | **Revised:** 19 December 2024 | **Accepted:** 22 December 2024

Funding: This work was supported by the Movement and Ecology of Flapper Skate (MEFS) and INTERREG VA (Special EU Projects Board) Marine Protected Areas Monitoring and Management project.

Keywords: autonomous underwater vehicle | elasmobranchs | habitat | spawning grounds

ABSTRACT

To implement effective management and conservation strategies, an understanding of the spatial ecology, habitat preferences and movement of demersal elasmobranchs is required. This study combines a photographic survey obtained from an autonomous underwater vehicle (AUV) with existing bathymetric data to help understand elasmobranch ecology within the Firth of Lorn, western Scotland. This area is within the Loch Sunart to Sound of Jura Marine Protected Area (MPA) and designated for the protection of the critically endangered flapper skate (*Dipturus intermedius*). Two areas of seabed were surveyed using an AUV in water depths of 110–165 m southwest of the Isle of Kerrera. Eight surveys were conducted in total, four in each area. Each area was surveyed twice over 2 days in October 2020 and twice in 2 days in May June 2021. One day used bait on the seabed (October) whilst all the others had no bait. For each survey, the AUV travelled 17 km at a height of 2 m above the seabed in a lawnmower pattern providing 0.5 km^2 photographic coverage for ~2 h per survey. Five elasmobranch species, two scyliorhinids (*Scyliohinus canicula* and *Galeus melastomus*) and three rajiformes (*D. intermedius*, *Raja clavata* and *Leucoraja naevus*), were identified from a total of 43 k seabed photographs. In total 42 individual animals and 7 egg cases were observed. Although the AUV had short survey times and small study areas the results are encouraging for AUVs being a useful tool in understanding elasmobranch ecology.

1 | Introduction

An understanding of the spatial ecology, habitat use and movements of elasmobranchs is becoming increasingly important, as many species have large neonatal size, low parturition and late maturity rates and a long-life expectancy (Bache-Jeffreys et al. 2021; Ebert and Stehmann 2013) which make them susceptible to over-exploitation. This has resulted in significant range reductions and the complete regional disappearance of some species (Bache-Jeffreys et al. 2021). Conservation efforts have focussed on measures to reduce by-catch in fisheries, but also spatial management to protect refugia from both targeted and incidental fishing. Implementing effective spatial management however requires a good understanding of the preferred habitat for the species of interest, which itself may change for different life stages.

The specific local habitat selectivity of demersal elasmobranchs is an understudied area largely due to the difficulties in recording in situ data for demersal elasmobranchs which has resulted in a lack of species-specific data. This knowledge gap is a potential barrier to conservation as understanding a species spatial ecology, including habitat preferences and migratory behaviours, are essential to implement effective management and conversation strategies (Thorburn et al. 2021). Historically, mapping demersal elasmobranch occurrence has been largely based on bottom-trawl data (Martin et al. 2012; Skomal et al. 2017; ICES 2023). Because tows are often quite widely spaced these surveys provide broad spatial patterns, but fish abundances are averaged along the tow length which can complicate interpretation of preferred habitats in heterogeneous environments. Trawl surveys are also normally designed to avoid areas of hard ground, limiting knowledge on species use of these habitats. Furthermore, it may be impractical to use trawl surveys in Marine Protected Areas due to limitations of protective measures and their potential to cause habitat damage to protected features. These limitations require alternative, ideally noninvasive techniques, to be used to monitor such areas (Benjamins, Dodd, et al. 2018).

Recent advances in technology have seen increasing application of telemetry to elasmobranch studies, for example, biologging tags such as pop-up satellite-linked archival tags (PSATs) (Skomal et al. 2017), acoustic transmitters and 'smart' position or temperature transmitting (SPOT) tags (Franks et al. 2021). Such methods have greatly increased our understanding of the movements of individual sharks (e.g., Hammerschlag, Gallagher, and Lazarre 2011; Schaber et al. 2022; Renshaw et al. 2023; Thorburn et al. 2023), skates (e.g., Kneebone et al. 2020; Lavender et al. 2022) and rays (e.g., Brewster et al. 2021). The results from telemetry studies are often combined with independent environmental information to infer, often broad scale, habitat preferences. Such analyses have often selected depth, bed shear stress and salinity followed by seabed sediment type and temperature as the main drivers of habitat selection (Harcourt et al. 2019).

However, telemetry has several limiting factors that do not allow accurate quantitative investigations into local habitat selectivity and these technologies are better suited to investigations into broadscale habitat preference. For biologging tags, locations are estimated using geolocation techniques, which can introduce high levels of uncertainty. Acoustic transmitting tags are limited in their ability to provide movement data based on the extent of the acoustic receiver array and while the spatial resolution from acoustic studies is often finer than that produced from biologging technology, local habitat selectivity is still difficult to infer due to estimated positions (Lavender et al. 2022). Another confounding factor is a limitation in the amount of habitat data available, especially at an oceanic scale as only 25% of the global seafloor has been mapped to a spatial resolution comparable to terrestrial studies (Boswarva et al. 2018). This limits the opportunity for matching animal movement to specific habitat types.

To address the limitations of telemetry studies, Baited Remote Underwater Video Systems (BRUVS) are increasingly being used to study elasmobranchs (e.g., Benjamins, Dodd, et al. 2018; Benjamins, Fox, et al. 2018; McGeady et al. 2023). These systems offer noninvasive means to observe species presence, behaviour and relative abundance across various habitats and depths (Harvey et al. 2007; Cappo et al. 2003). The advantages of BRUVS are that they survey specific areas and provide visually quantifiable data on not only species presence and abundance but also the local habitat. They are particularly valuable in challenging environments where traditional methods struggle to reach, providing visual records without disturbing the animals (Whitmarsh, Fairweather, and Huveneers 2018). To design an effective BRUV survey that captures all local habitat types, detailed habitat information must be obtained beforehand. This requirement becomes particularly critical in highly heterogeneous environments, where the diversity and complexity of habitat types present significant challenges for comprehensive survey coverage. This requirement can limit the effectiveness of BRUV surveys. Another factor that must be account for in BRUV surveys is that bait is used to attract species to the cameras, potentially skewing data towards opportunistic feeders (Harvey et al. 2007). The system's field of view and deployment duration also influence data comprehensiveness, limiting insights into population densities and precise spatial distributions (Cappo et al. 2003). Despite these constraints, BRUVS remain indispensable tools in marine ecology, offering insights into elasmobranch behaviour and habitat preferences that are otherwise difficult to obtain (Whitmarsh, Fairweather, and Huveneers 2018; McIvor et al. 2022).

The rapid advances in robotic and imaging technology coupled with decreasing cost offers an opportunity to investigate local habitat selectivity in demersal elasmobranchs by using autonomous underwater vehicles (AUVs) to address some of the limitations of existing survey methods detailed above. AUVs can collect spatially accurate occurrence data through imagery, whilst providing quantitative data on habitat, which is an advantage over vessel-based observations. In addition, the location of an AUV during a survey is accurate, the images collected can reliably be spatially referenced at a high resolution, promoting their use in collecting data to inform on local habitat selectivity. The ability to cover large areas during a single deployment offers and advantage over BRUVS, as images from throughout a survey areas can be collected during a low number of deployments. Finally, due to the programmable nature of AUVs, they offer the potential to undertake repeatable surveys which, if surveys are carried out at multiple points over the course of year, might reveal seasonal variations in species distribution or behaviour. Finally, AUVs are largely noninvasive, and the development of noninvasive methods is especially relevant in managed protected areas where other survey techniques could be restricted. AUVs have been successfully used to track large elasmobranchs, such as basking sharks, providing real time video footage of these animals move and interact with their environment over short periods of time (Hawkes et al. 2020). AUVs have also been used in conjunction with other methods, such as acoustic telemetry (Clark et al. 2013) to provide insight into habitat use of marine species, but their ability to collect suitable image to investigate the presence, species assemblage and habitat association of benthic and demersal elasmobranchs is largely unexplored.

The Loch Sunart to the Sound of Jura Marine Protected Area on the west coast of Scotland covering 741 km^2. This MPA is designated for the protection of the Flapper skate (*Diputrus intermedius*) and there is a ban on mobile fishing gear throughout much of the site. The area has been shown to have a high density of skate that exhibit residential behaviour (Neat et al. 2014; Régnier et al. 2024), and there is a comprehensive background regarding the species habitat use within the area based on

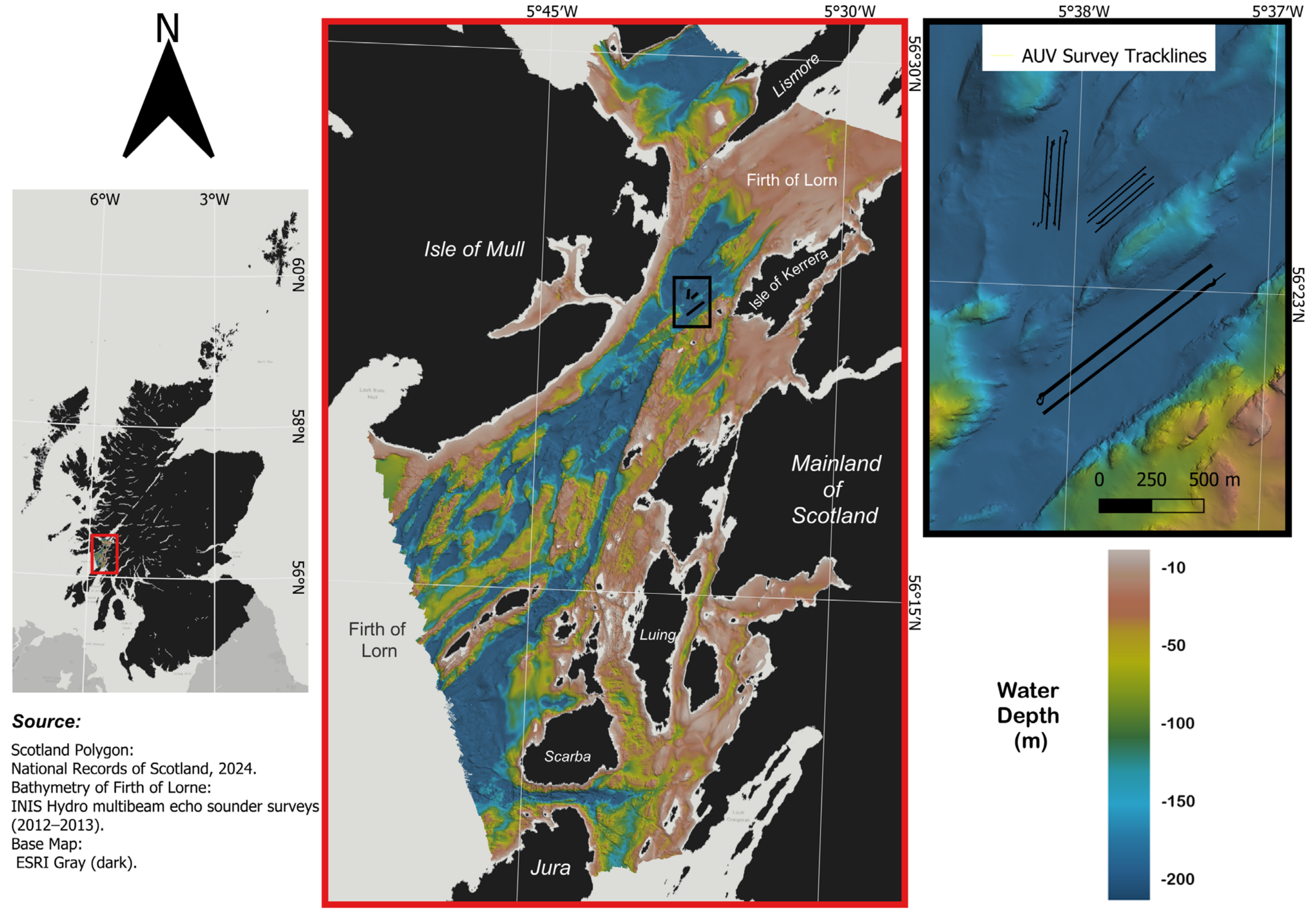


FIGURE 1 | Location of the Firth of Lorn, West of Scotland, UK with inset (red box) showing the AUV survey area within the regional bathymetry of the Firth of Lorn (from the Irish, Northern Irish and Scottish Seabed Survey (INIS Hydro Project; Howe et al. 2015). AUV mission survey lines. The northern survey (divided into two discrete surveys) separated by a submarine ridge and the southern site.

telemetry data (Thorburn et al. 2021; Lavender et al. 2022) and, more recently, BRUVS (Benjamins, Dodd, et al. 2018; Benjamins, Fox, et al. 2018). The MPA appears to foster site association behaviours in flapper skate, as evidenced by acoustic telemetry studies demonstrating patterns of residency, site fidelit and transiency in the species (Neat et al. 2014; Lavender et al. 2022). Previous acoustic telemetry studies indicate that nearly half of the tagged individuals exhibit long-term residency within the MPA, often lasting from 3 to over 12 months, with females showing higher levels of site fidelity than males (Lavender et al. 2022). Localised movement patterns within the MPA are influenced by environmental factors such as water depth, salinity and seasonal changes, with individuals often showing fidelity to specific areas of the MPA. The deep-water trench system within the MPA serves as a particularly important habitat, especially during the winter months (Thorburn et al. 2021). While flapper skate are found throughout the MPA's full depth range (1–312 m), they show a preference for depths between 20 and 225 m (Thorburn et al. 2021). Seasonal and ontogenetic depth preferences are evident, with skates favouring the deep trench habitats during summer and shifting to shallower waters in winter. This seasonal shift is particularly pronounced in mature females, who are frequently observed in depths of 25–75 m during winter, suggesting distinct life stage-specific habitat requirements (Thorburn et al. 2021). These findings collectively underscore the dynamic habitat needs of flapper skate and the critical role of the MPA in their conservation. Despite this understanding of the species habitat use within the MPA, there is a lack of knowledge for the early life history stages of this species; both within the MPA and throughout its range due to the difficulties in surveying this life history stage with more traditional techniques (Garbett et al. 2020). With regard to tagging studies, there is a bias towards larger animals due to the size of the tag technology and lack of interactions with smaller skate in these studies. Within the MPA there are limited opportunities to undertake trawl surveys due to the protective measures in force.

To address knowledge gaps regarding skate within the MPA and evaluate the effectiveness of autonomous underwater vehicles (AUVs) as a complementary tool for investigating habitat selectivity in demersal elasmobranchs, we deployed an AUV to conduct surveys within the MPA. The AUV captured in situ photographs, which we analysed to examine the habitat selectivity of all life history stages of flapper skate.

2 | Study Area

The Loch Sunart to the Sound of Jura Marine Protected Area (LStSoJ MPA) incorporates areas of the Firth of Lorn and the

Sound of Jura on the West coast of Scotland. The Firth of Lorn, western Scotland is a coastal deep-water fjord between the south-east coast of Mull and mainland Scotland. The Firth extends from the southwestern end of Lismore to the west of Jura (Howe et al. 2015) (Figure 1). The region is bathymetrically complex, comprising a bedrock-dominated seabed divided into narrow, glacially over-deepened basins reaching more than 200 m deep in places (Howe et al. 2015). Seabed sediments are predominantly muddy, with rocky, sandy and gravelly substrate found over localised areas (Howe et al. 2015). The dominant habitat types are moderate energy circalittoral rock (CR.MCR), sublittoral mixed sediment (SS.SMx) and sublittoral sand and sand mud (SS.SSa) (Seabed sediments and associated derived habitat maps can be found in Boswarva et al. 2018).

3 | Materials and Methods

3.1 | Survey Design

Surveys were conducted from the R.V. Seol Mara on the 20th and 21st October 2020 and on 31st May and 1st June 2021. The study took place within the inner Firth of Lorn southwest of the Isle of Kerrera in water depths of 110–165 m (Figure 1). The area was selected as it is a well-known sea angling site for flapper skate. One baited and three nonbaited surveys were conducted for each area, with the bait only being used on the first survey. The first surveys (20th October) were baited using approximately 5 kg of mackerel (*Scomber scombrus*) in an open mesh string bag weighted to the seabed. The latter six surveys were unbaited.

3.2 | Survey Locations

Two sites were surveyed, a northern and southern site. The first AUV site (south) was across a relatively flat basin in water depths of 158–164 m. The second site (north) was a single continuous survey divided into two components, east and west of a bathymetric ridge (Figure 1). The presence of the ridge dictated planning two elements to one survey to protect the AUV from an underwater collision with the ridge. Water depths at these northern sites varied from 125 to 160 m. Each area was surveyed four times (for a total of eight surveys). Each individual survey repeated a simple 'lawnmower' pattern to a total seabed distance travelled of approximately 17 km. The regional bathymetry for survey planning was provided by the Ireland, Northern Ireland and Scotland (INIS) Hydrographic Survey (Howe et al. 2015). Tidal currents are mostly weak across both the survey areas with currents of 0.1–0.45 m/s (Admiralty Chart 2387, 1976).

3.3 | AUV Configuration

A Teledyne 'Gavia' Offshore Surveyor vehicle was run at a constant height of 2 m above the sea floor. In addition, opportunistic bathymetry and side scan data were obtained using a Kongsberg 500 kHz GeoSwath+ interferometric bathymetric side scan sonar mounted on the AUV. The AUV camera was a Grasshopper benthic low light camera. Underway ambient temperature, seawater density, and depth data were also obtained along the vehicle track. For each survey (north and south), approximately 5 thousand seabed images were collected. Over the 4 days, a total of approximately 43 thousand images were obtained. If the vehicle is travelling too fast the seabed photographs will be blurred, but if travelling too slowly the vehicle will struggle against the tide. For these surveys a vehicle 'work rate' of 650 rpm was chosen, equating to approximately 0.3 m/s over the seabed. Photographs were recorded at one image per second, which, depending on fluctuations in vehicle speed, provided a near-continuous seabed coverage along the survey lines.

3.4 | Data Processing

Underway bathymetry and side scan data provided a very detailed view of the seabed but only along a narrow strip (~6 m width) beneath the vehicle. The bathymetry and side scan data were processed using Caris HIPS and SIPS v.11. Seabed photographs were processed (colour balance, vignetting removed and contrast enhanced where required), and their metadata extracted using Spyder, an open-source scientific programming software in Python. Photographs were manually and individually viewed to identify seabed sediment type, and elasmobranch species present which were recorded in a spreadsheet. All the occurrence data from the photographs were then visualised into a combined seabed map using QGIS, an open-source cross-platform desktop geographic information system (GIS) application.

4 | Results

4.1 | Habitat Structure

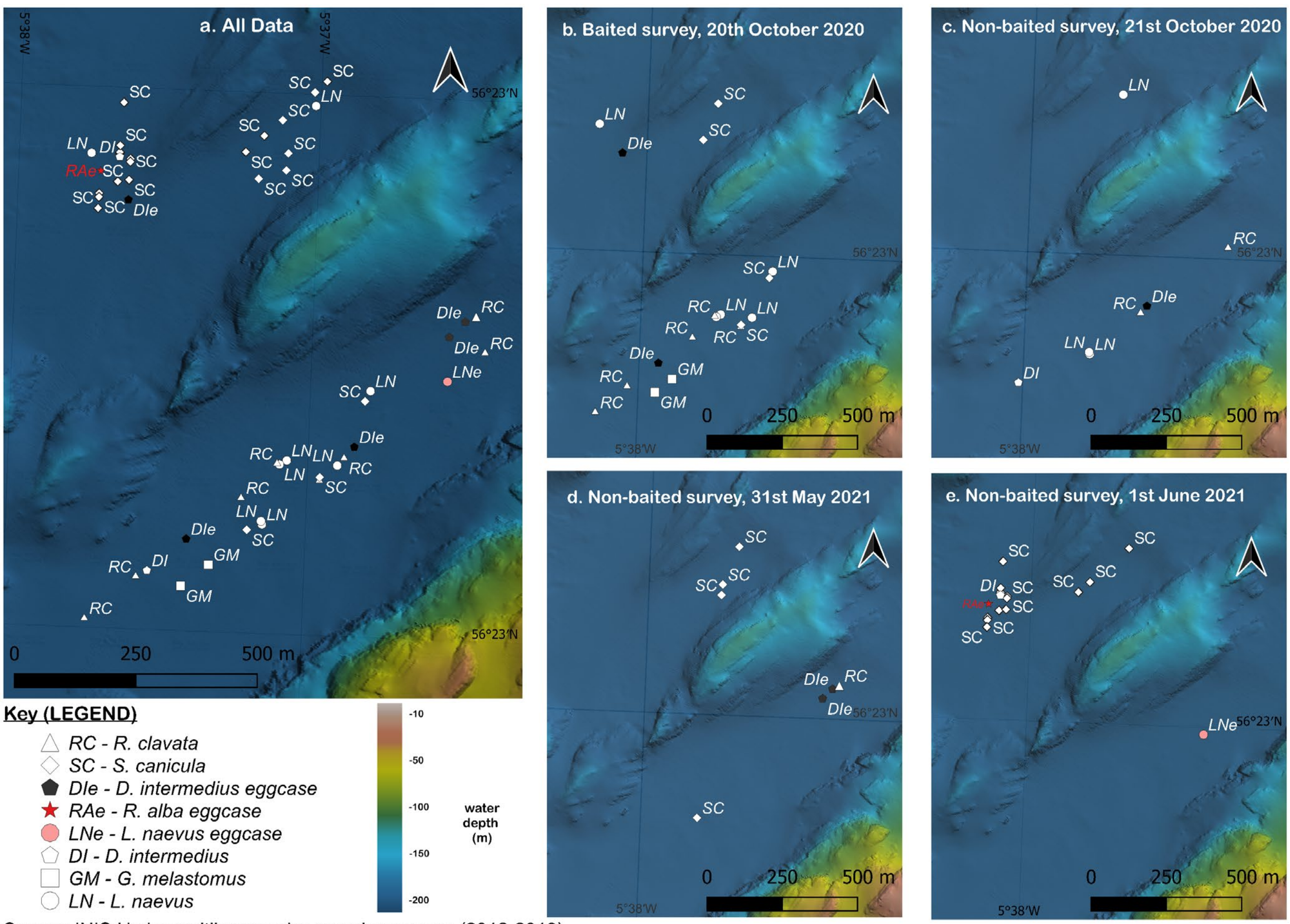
Based on a visual assessment of the seabed photographs, the seabed sediment and biotope of the northern site were very similar to the southern site, although there were larger numbers of scattered boulders, and some exposed bedrock. There were also small areas where coarser substrates were seen creating small gravel patches between the finer sediment types. SS.SMx and SS.SSa were once again the dominant biotopes (Boswarva et al. 2018) and as such there was no difference in faunal assemblage from the southern site, so other biotopes such as burrowed mud and brittlestar beds were also likely present. The underway side scan sonar and bathymetry provided additional data on the seabed sediments. Whilst these data are not explicitly referred to in this study these data were incorporated into the general assessment of the seabed habitats.

4.2 | Underway Survey Conditions

Autumn months typically provide the warmest sea temperatures whilst the spring and early summer the coldest. During the October 2020 surveys, for example, the AUV recorded a sea surface temperature was 13.2°C with the same temperature at 160 m depth. Density at depth ranged from 1025 to 1026 kg/m^3. For the May and June 2021 missions, the sea surface temperature was around 9.7°C with the depth temperature ranging from 9.3°C to 9.4°C. Density records at depth ranged from 1026 to 1026 kg/m^3.

TABLE 1 | Species observed, numbers of individuals, the dates and times of observations.

Date and time of photo survey (ID)	20/10/20 (ID 1 & 2)	21/10/20 (ID 3 & 4)	31/05/21 (ID 5 & 6)	01/06/21 (ID 7 & 8)	
	09:34–12:24 h	08:40–11:43 h	10:16–12:40 h	09:30–11:05 h	
Species	**Baited**				**Total**
Dipturus intermedius		1		1	2
Raja clavata	5	2	1		8
Leucoraja naevus	5	3			8
Galeus melastomus	2				2
Scyliorhinus canicula	4		4	14	22
Dipturus intermedius (egg case)	2	1	2		5
Rostroraja alba? (egg case)				1	1
Leucoraja naevus? (egg case)				1	1



Source: INIS Hydro multibeam echo sounder surveys (2012-2013).

FIGURE 2 | (a) All elasmobranch and egg case records from all surveys within the study area. (b) Baited survey observations from the 20th of October 2020 (ID 1 & 2). (c) Nonbaited survey observations from the 21st of October 2020 (ID 3 & 4). (d) Survey from 31st of May 2021 with observations (ID 5 & 6). (e) Survey observations from the 1St of June 2021 (ID 7 & 8).

4.3 | Summary Demersal Elasmobranch Species Counts

Overall, five species of demersal elasmobranch were recorded during the surveys. The catshark *S. canicula* (*n*: 22) was the most common with three adults and 19 juveniles observed, by the two Rajiformes *L. naevus* (*n*: 8) and *R. clavata* (*n*: 8) and the catshark *G. melastomus* (*n*: 2) (Figure 3 and Table 1). Two individual *D. intermedius* were observed, one adult and one juvenile and five *D. intermedius* egg cases were also recorded. Two other Rajiform egg cases were also observed. The first egg case was large and subquadrate, the horns were relatively thick and curved inward with the anterior horns being longer than posterior horns. The observation could be a de-skirted *D. intermedius* egg case. The smaller of the two unidentified egg cases most resembled that of *L. naevus* which measure 5–7 cm long and 3–5 cm wide (excluding the horns), with weakly striated but smooth surfaces and the anterior pair of horns very elongated, about twice the length of posterior horns and longer than the egg case proper (Ebert and Stehmann 2013).

Overall, the number of individuals observed at both sites were similar (southern [*n*: 20] and northern [*n*: 22]), (Figure 2a and Table 2). However, most of the observations from the northern site were juvenile *S. canicula* (*n*: 19) with *L. naevus* (*n*: 2) and a single juvenile *D. intermedius*. At the southern site both species and individual observations were more diverse with *L. naevus* (*n*: 6) and *R. clavata* (*n*: 8) and *G. melastomus* (*n*: 2) and a single adult *D. intermedius*.

4.4 | Non Elasmobranch Species

The southern site was dominated by burrowing cnidarians, along with Norway lobster (*Nephrops norvegicus*) and Rugose squat lobster (*Munida rugosa*). Large numbers of ophiuroids, mixed with Common starfish (*Asterias rubens*), Common sun star (*Crossaster papposus*), Purple sun star (*Solaster endeca*), Seven-armed starfish (*Luidia ciliaris*), Red cushion star (*Porania pulvillus*) and the Edible sea urchin (*Echinus esculentus*) were also seen, alongside crustaceans like the Edible crab (*Cancer pagurus*) and Common hermit crab (*Pagurus bernhardus*). Several teleost fish were also identified, predominantly small to medium-sized Gadiformes and a small number of flatfish (*Pleuronectiformes*), although with a single large European conger eel (*Conger conger*) and one possible Common ling (*Molva molva*).

4.5 | Survey Results

During the 20th of October 2020 baited survey (ID 1 & 2), four species and 16 individual animals were observed in total. The two smaller Rajiformes, *R. clavata* and *L. naevus* being the most common (*n*: 5). The only two *G. melastomus* recorded from all the surveys were present on this date (Figure 2b and Table 1). All the elasmobranchs observed were located at the southern site (Figure 2b and Table 2). In addition, two *D. intermedius* egg cases were also identified, one in the northern and one in the southern site. The presence of the bait clearly attracted elasmobranchs with more observations of *R. clavata* (baited *n*: 5; nonbaited *n*: 3), *L. naevus* (baited *n*: 5; nonbaited *n*: 3) and *G. melastomus* (baited *n*: 2; nonbaited *n*: 0), (Tables 1 and 2, Figure 3a,b).

On the first nonbaited survey on the 21st of October 2020 (ID 3 and 4), (Figure 2c and Tables 1 and 2). Overall, three species and six individuals were observed *L. naevus* (*n*: 3) and *R. clavata* (*n*: 2) were the most common species observed. The only adult *D. intermedius* was observed during this survey (Figure 3d) and a single *D. intermedius* egg case also identified. Apart from one *L. naevus*, all the elasmobranchs were located on the soft sediment of the southern site (Tables 1 and 2).

The second nonbaited surveys took place 8 months later, on the 31st of May 2021 (ID 5 & 6) (Figure 2d and Tables 1 and 2). Only

TABLE 2 | Elasmobranch occurrence, sites and dates.

Species/date	Northern site (56.387 N, −5.624 W, 56.387 N, −5.623 W, 56.389 N, −5.618 W, 56.309 N, −5619 W) (56.387 N, −5.628 W, 56.387 N, −5.626 W, 56.391 N, −5.625 W, 56.391 N, −5.627 W)				Southern site (56.380 N, −5.627 W, 56.379 N, −5.627 W, 56.386 N, −5.614 W, 56.385 N, −5.613 W)			
	2020		2021		2020		2021	
	20/10 (ID 2)	21/10 (ID 4)	31/10 (ID 6)	01/06 (ID 8)	20/10 (ID 1)	21/10 (ID 3)	31/05 (ID 5)	01/06 (ID 7)
Survey ID	Baited				Baited			
Dipturus intermedius				1		1		
Raja clavata					5	2	1	
Leucoraja naevus	1	1			4	2		
Scyliorhinus canicula	2		3	14	2		1	
Galeus melastomus					2			

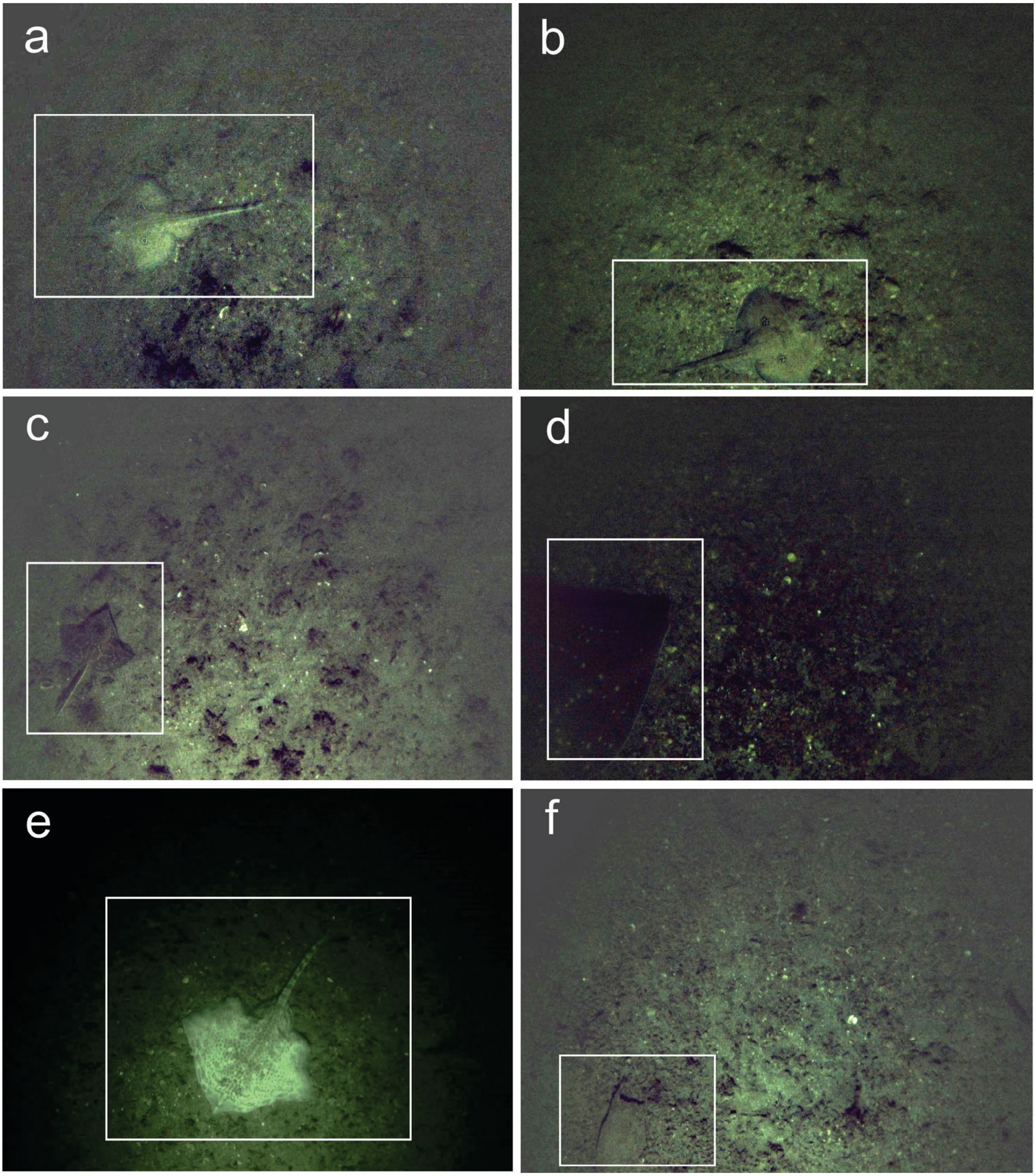


FIGURE 3 | Selection of AUV underway seabed photographs showing (a) *Leucoraja naevus* from the southern site on 20 October 2020 (ID 1), (b) *L. naevus* from the southern site from the 20th October 2020 (ID 1), (c) the single juvenile *Dipturus intermedius* at the northern site on 1st June 2021 (ID 3), (d) the only adult *D. intermedius* observed from the southern site on the 21st October 2020 (ID 4), (e) *Raja clavata* from the southern site on the 31st May 2021 (ID 5), (f) an *D. intermedius* egg case from the northern site on the 31st May 2021 (ID 6).

two species were observed, *R. clavata* (*n*: 1) (Figure 3e) and *S. canicula* (*n*: 4) although, two *D. intermedius* egg cases were also identified (Figure 3f). The northern site had more individuals than the southern site, all of which were juvenile *S. canicula* (*n*: 3), a single *R. clavata*, one adult *S. canicula* and a *D. intermedius* egg case were observed at the southern site. Noted were the differences in the location of juvenile and adult *S. canicula*, on the 20th of October 2020 and the 31st of May 2021. All the juvenile *S. canicula* were observed at the northern site, and all the adults at the southern site.

Further nonbaited surveys took place the next day, the 1st of June 2021 (ID 7 & 8). Two species were observed, a juvenile *D. intermedius* (*n*: 1) (Figure 3c) and *S. canicula* (*n*: 14), two Rajiform egg cases was also observed (Figure 2e and Tables 1 and 2), both being possibly *R. alba* and *L. naevus*. All elasmobranch observations were from the more northern site with only the single possible *L. naevus* egg case being recorded at the southern site. All the *S. canicula* and a single *D. intermedius* observed at the northern site were juveniles.

5 | Discussion

The results of this pilot study suggest that AUVs could provide a noninvasive observational tool to help understand elasmobranch ecology. While the data reported here are limited in terms of geographic extent and timeframe, they do highlight the capability of AUVs in future elasmobranch research and compliment other numerous telemetry-based observations. Within the LStSoJ MPA this study provides data on elasmobranch occurrence and habitat which did not require fishing and extends and enhances the observations which could be collected via BRUV deployments. The utility of the AUV approach is in the ability of the vehicle to provide repeatable, underway in situ observations whilst also collecting additional datasets such as bathymetry and oceanographic measurements. Here we show how an AUV can observe a variety of elasmobranch occurrence, including the critically endangered *D. intermedius*, their habitat and spatial extent from eight surveys over 2 years. This study is not able to provide any data to suggest that indirect observations from AUVs do not influence elasmobranch behaviour (such as frightening the animals with the flashing strobe). A previous study from the Chilean Patagonia, also using this AUV, suggests that AUVs do not elicit strong adverse reactions when used to monitor elasmobranchs (Boswarva et al. 2018). In addition, AUVs could be used to inform managers and policy makers about elasmobranch habitat at different stages of their complex life histories. Finally, the positional accuracy, spatial coverage and scale achievable means that targeted surveys can be used to build information on critically important knowledge gaps such as egg nursery and neonatal habitats.

The increased elasmobranch sightings during the baited surveys suggested that the use of bait did act as an attractant. Specifically, there were more observations of *R. clavata*, *L. naevus* and *G. melastomus* during the baited surveys. *G. melastomus* especially were only observed when bait was present. Almost all the demersal elasmobranchs observed were located on the soft burrowed mud at the southern site. However, observations 8 months later, show only two species, *R. clavata* and *S. canicula* were present. Also, both *D. intermedius* egg cases and single *R. clavata* were also observed at the southern site as was the only adult *S. canicula*. Only two species were observed at the northern site, a juvenile *D. intermedius* and *S. canicula*. Two Rajiform egg cases was also recorded; however, both proved difficult to identify from the photographs. In contrast to the previous surveys in the spring, all elasmobranch records came from the northern site in the autumn.

Three adult and 19 juvenile *S. canicula* were observed, with two adults and two juveniles in 2020, and one adult and 17 juveniles in 2021. All the adults were recorded at the southern site, and all the juveniles recorded at the northern site. Perhaps this is a form of predator avoidance strategy (Simpson, Sims, and Trueman 2019). Juveniles could escape predation by using the increased rock cover at the northern site. *D. intermedius* showed a similar pattern with a single juvenile from the northern site and a single adult at the southern site. This species is known to have seasonal variations in depth (Thorburn et al. 2021) which could extend to habitat preferences.

The occurrence of *D. intermedius* egg cases and an individual juvenile is encouraging signs of an egg nursery. The habitat preferences of neonatal *D. intermedius* have not previously been identified within the LStSoJ MPA (Dodd et al. 2022) despite heavily pregnant females having been recorded within the region (Benjamins et al. 2021; Dodd et al. 2022). Other areas that have been identified as *D. intermedius* egg nurseries, such as the Red Rocks and Longay MPA (Dodd et al. 2022) and the Orkney Isles (Phillips et al. 2021) have been characterised as being shallow depths (< 100 m) with low sedimentation, over boulders and exposed bedrock and with moderate current flows (15–140 cm/s) (Dodd et al. 2022; Phillips et al. 2021). This study does not possess these habitats, being mainly > 100 m in deep and characterised by high sedimentation, with little exposed bedrock or extensive boulder fields. All five egg cases were observed on soft sediments. One at the northern site and four at the southern site. However, it was not possible to determine whether the egg cases were still viable or empty (posthatching).

Typically, eggs would occur in at least pairs (Thorburn et al. 2023) and on rocky sites (Dodd et al. 2022; Phillips et al. 2021). Whilst be unable to determine the viability of eggs is a limitation, the density of eggs at known egg-laying sites and the ability of AUV imagery to detect egg cases, the method could be used in the initial identification of egg nurseries for egg-laying elasmobranchs. The sighting of the juvenile does build upon the limited evidence we have of juvenile *D. intermedius* using mud habitats within the LStSoJ MPA (MEFS project, unpublished data) and supports the concept that juvenile *D. intermedius* move away from egg nurseries after hatching (Dodd et al. 2022). The potential for AUVs to provide information on this data-deficient life history class is encouraging for future studies. While we did not survey habitat associated with *D. intermedius* egg-laying grounds, the evidence suggests that such habitat does exist in the area and that an egg-laying nursery could be close by. Two other egg cases were also observed during the survey, but again both are difficult to identify. Both egg cases were recorded on the 1st of June 2021 with the larger egg case found at the northern site and the smaller of the two present the southern site.

The results from this pilot study suggest that AUVs could be particularly well-suited for surveying demersal elasmobranchs in areas like the LStSoJ MPA. The MPA encompasses deep water, energetic tidally currents within a bathymetrically complex region. Traditional methods (e.g., BRUV or angling) can struggle to gather spatially accurate comprehensive data. In this study the AUV operated at depths of 110–165 m, efficiently and accurately navigating and collecting data, including underway seabed photographs. Within the MPA, a ban on mobile fishing gear, such as trawling, necessitates a nonintrusive approach, making AUVs ideal as they reduce or negate disturbing the seabed or its inhabitants. AUVs are designed to operate in challenging conditions, including areas with high currents, where deploying and manoeuvring other survey tools would be logistically difficult. While BRUVS have been used in the area (Benjamins, Dodd, et al. 2018; Benjamins, Fox, et al. 2018), they have limited capability in deeper, tidal environments. BRUVS can attract a limited range of species and provide only static point observations (Whitmarsh, Fairweather, and Huveneers 2018; McGeady et al. 2023), while in contrast, an AUV covers a broad regional area and provides a wealth of additional underway data on animals in situ. Tracking studies in the region have provided a wealth of information on *D. intermedius*, but their habitat associations have previously only been estimated (Thorburn et al. 2021; Lavender et al. 2022). The seabed images from the AUV indicate that these vehicles are able to undertake surveys that generate data on habitat association across the species life history. However, the paucity of existing data to compare to these findings to does caution against over-interpretating these new data. Although the data are from this study is limited, the AUV provides valuable 'snapshots' of elasmobranch occurrence and habitat. The ability of these vehicles to provide repeatable, highly accurate, autonomous surveys could open new insights into demersal elasmobranch ecology.

Acknowledgements

This research was funded through the Marine Protected Area Monitoring and Management (MarPAMM) project and was supported by the European Union's INTERREG VA Programme, managed by the Special EU Programmes Body (SEUPB) and the Movement Ecology of the Flapper Skate (MEFS) project funded by NatureScot (project code: 015960), Marine Scotland (project codes: SP004 and SP02B0) and the Marine Fisheries Fund (project code: SCOMFF1006). MarPAMM received matching funding from the Government of Ireland, the Northern Ireland Executive, and the Scottish Government. The authors would like to thank Colin Abernethy, Lewis Drysdale, Estelle Dumont & Nicol McCallum (AUV pilots and data processing) and Norman Smith (RV Seol Mara captain).

Conflicts of Interest

This paper presents the results of a noninvasive, observational pilot study on elasmobranchs. The study was jointly funded by the Marine Protected Area Monitoring and Management (MarPAMM) project (supported by the European Union's INTERREG VA Programme, managed by the Special EU Programmes Body [SEUPB]) and the Movement Ecology of the Flapper Skate (MEFS) project funded by NatureScot (project code: 015960), Marine Scotland (project codes: SP004 and SP02B0) and the Marine Fisheries Fund (project code: SCOMFF1006). There are no conflicts of interest in the authorship team.

Data Availability Statement

All the data are freely available from the authors upon request.

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