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Movement Ecology of the Flapper Skate

PROJECT REPORT

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Photo of a flapper skate in Scottish waters. ©Steven Bradley.

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Contents

A tagged flapper skate being released. ©Jane Dodd/NatureScot

Executive summary and management advice

- Flapper skate display a high level of site attachment to the Loch Sunart to the Sound of Jura (LSSoJ) MPA. This includes year-round residency, more notably in female skate, short term residency and site fidelity in both sexes. Residency of 3 months or more was observed in ~ 50% of the skate studied, including individuals in all studied life-history stages (>110 cm total length), suggesting a high proportion of skate in the LSSoJ MPA may benefit from management measures throughout the year. The MPA appears, to some degree, to have the potential to benefit all life-history stages. A better understanding of how small juvenile skate use the area would allow for a complete assessment of the site for all life-history stages.
- The current boundaries of the LSSoJ MPA appear suitable, incorporating most of the deep trench systems that predominate in the region. The areas of deep water to the south of the LSSoJ MPA boundaries in the Firth of Lorn and the Sound of Jura have depths consistent with the skate's summer core depth range. Gaining insight into the level of commercial fisheries interactions with flapper skate in these areas would be of high interest.
- Skate show seasonal variation in depth use, using deeper water (> 100 m) over summer and shallower water (< 100 m) on average over winter. Interactions between skate and fisheries in water shallower than 50 m are less likely over summer than in winter. However, both within the LSSoJ MPA and in other locations, egg nursery habitat has been identified in waters 20 -60 m deep, and the 18-month development time of skate eggs puts them at risk throughout the year in areas of the MPA where bottom contact mobile gear fishing is allowed. In lieu of detailed knowledge on the location of egg nurseries within the LSSoJ MPA, it is sensible that all shallow areas are protected throughout the year, as is currently the case.
- Skate are reproductively active in the LSSoJ MPA. It appears that skate may lay eggs over winter, but more data is needed to support this. The presence of females carrying encapsulated eggs suggests that there are egg-laying sites within the LSSoJ MPA. This is supported by diver observations of eggs in the LSSoJ MPA.
- Angling is associated with increases in physiological indicators of stress. Angling is also associated with short-term behavioural changes following release [including resting, elevated vertical activity and, in 14 % of individuals, irregular behaviour]. The long-term consequences of angling remain uncertain, but the high proportion of recaptured individuals in the MPA suggests that skate recover well following angling-induced stress. To mitigate the impacts of angling, best practice guidelines should be promoted and followed as much as possible. Anglers should aim to reduce fight and handling times, especially during months when the water is at its warmest. A study on the impact of angling on shore caught skate would be valuable.

Introduction

The flapper skate (*Dipturus intermedius*) is the largest skate species in European waters. The species is currently listed by the IUCN as Critically Endangered (Ellis et al., 2021) and is a Priority Marine Feature in Scotland due to severe population decreases and historic extirpation from some areas (Brander, 1981; Walker & Hislop, 1998), though the genus *Dipturus* is now showing signs of recovery (Rindorf et al., 2020), including the flapper skate (ICES 2020). In recent times, up until 2010, the flapper skate was known as the common skate (*Dipturus batis*). Genetic work published in 2010 showed the common skate to be a species complex comprising both the flapper skate (*D. intermedius*) and the common blue skate (*Dipturus batis*). The term common skate is still in use and is generally considered as referring to both species. This species confusion has challenged accurate species-specific range assessment. Currently, flapper skate distribution is known to encompass the southern coast of Norway, all Scottish coastlines, north-eastern England, the island of Ireland, northern France, Portugal and the Azores, with sites off the west coast of Scotland thought to be a stronghold for the species. The probability of occurrence is highest between 100 and 400 m depth (Pinto et al., 2016), with localised core depth ranges previously shown to be between 50–180 m in specific regions (Neat et al., 2014).

Flapper skate females are predicted to reach $L_{50\%}$ maturity at 21 years (estimated: 9–26 yrs). Males, in contrast, reach $L_{50\%}$ maturity at 14 years (7–16 yrs). Maximum age is estimated as >40 years for the largest individuals captured (Régnier et al., 2021). They have an estimated fecundity of 40 eggs per year (Brander, 1981). These life-history characteristics result in the species having a slow rebound potential. Current management measures for the common skate complex include an EU wide landing prohibition, prohibiting fishing, retention, transhipment, or landing. In Scotland, the species complex is on the Priority Marine Feature list, listed under The Sharks, Skates and Rays (Prohibition of Fishing, Trans-shipment and Landing) (Scotland) Order 2012, and is the designation feature of the Loch Sunart to the Sound of Jura Marine Protected Area (LSSoJ MPA).

The Loch Sunart to the Sound of Jura Marine Protected Area

The LSSoJ MPA covers a 741 km^2 area on the west coast of Scotland (Fig. 1) and includes a complex bathymetric environment. It is characterised by steep-sided trench systems, reaching up to 290 m in depth (Howe et al., 2014). Sediment types are predominantly mud, with rocky, sandy and gravelly habitats found over smaller areas (Howe et al., 2014; Boswarva et al., 2018). Water temperature varies over a year but is typically between 7.5 ^{o}C and 16 ^{o}C. There is a wide range of current velocities, reaching up to 4 m/s in the Corryreckan.

This site was proposed as an MPA for 'common skate' by the Scottish Sea Angling Conservation Network based on data from the Glasgow Museums and Scottish Shark Tagging Programme in 2011. The proposal was based on a large number of recaptures occurring within the area, suggesting a high level of site attachment. Subsequent passive acoustic telemetry research by Marine Scotland (Neat et al., 2014) supported this, and the site was designated in 2014 with a mix of spatial management measures (Fig. 2). Most of the site is closed to suction dredging, mechanical dredging, beam trawling, demersal trawling, and longline fishing. Some small areas allow dredging and trawling without a tickler chain (Fig. 2).

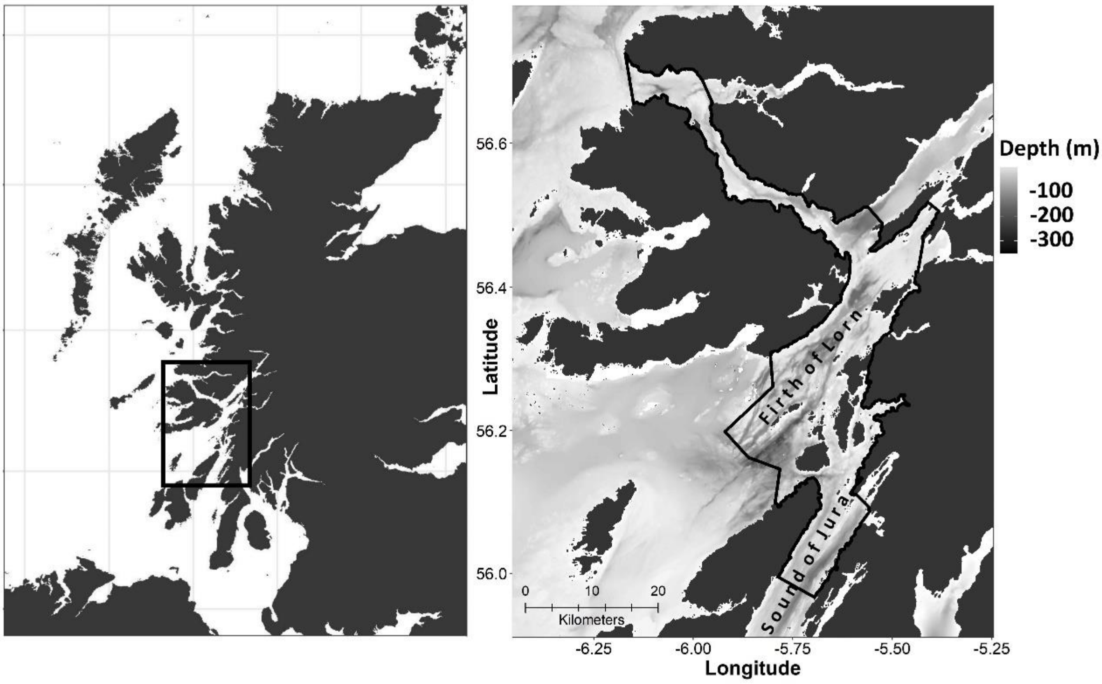

Figure 1: The location of the protected area covered by the Loch Sunart to the Sound of Jura Marine Protected Area and the Firth of Lorn SAC on the west coast of Scotland. The protected area is shown by the black line on the right-hand panel.

The Movement Ecology of the Flapper Skate (MEFS) project started in 2018 and aimed to provide more advanced analysis of passive acoustic and archival data collected in 2016/2017 (see Thorburn et al., 2018 for full details), providing information on space use within the LSSoJ MPA (Fig. 1) and the level of connectivity of this site to other areas. As part of MEFS, a second acoustic array was deployed to provide longer term site monitoring.

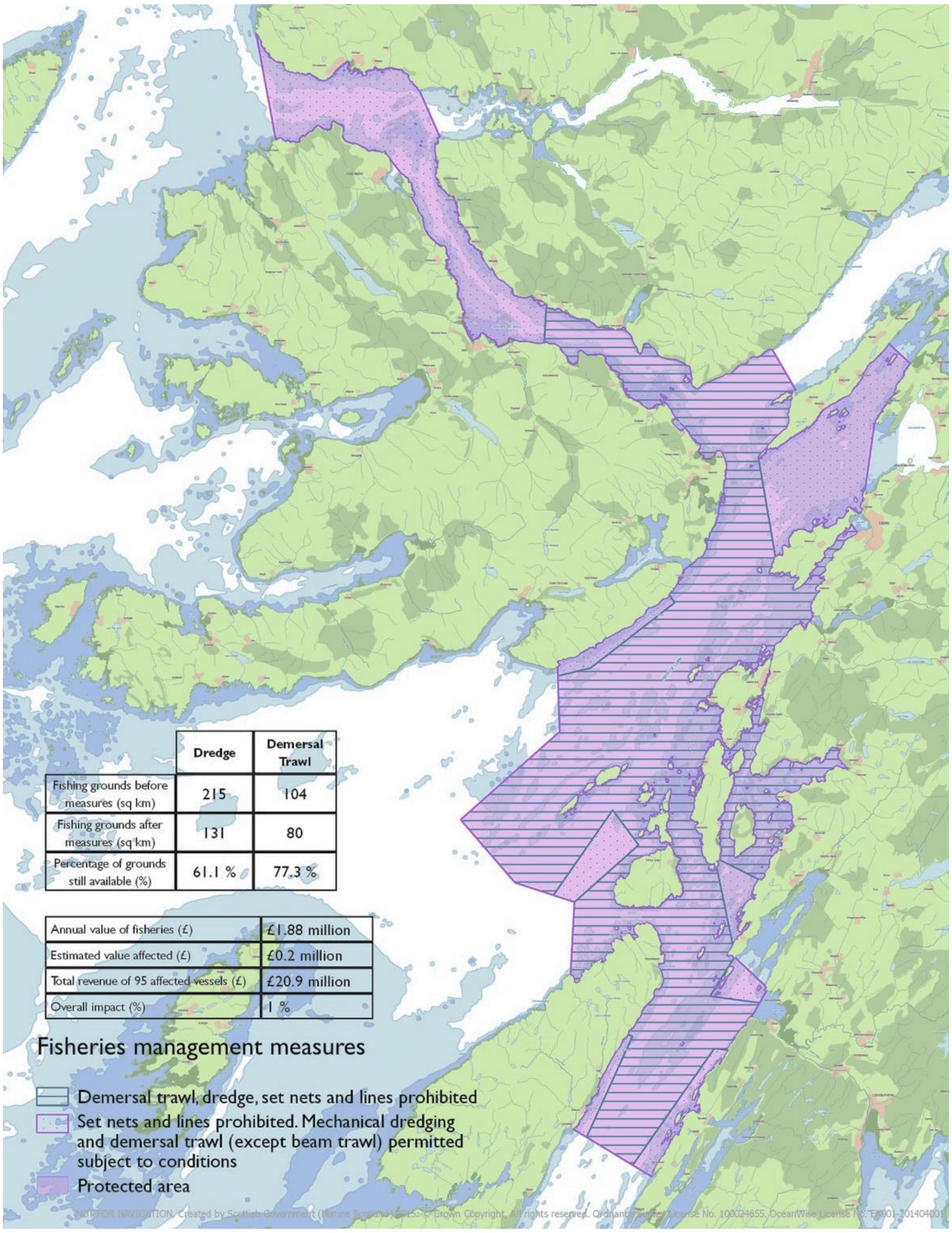

Figure 2: Management measures in the Loch Sunart to the Sound of Jura Marine Protected Area showing open and closed areas.

Movement Ecology of the Flapper Skate (MEFS) project

Residency patterns in the Loch Sunart to the Sound of Jura MPA and variation between life-history categories

This section summarises (Lavender et al., 2021b)*. All figures are adapted from this paper.*

Key findings

- Acoustically tagged individuals exhibited residency, site fidelity and transiency.
- Short-term residency, lasting at least three months, was documented in 13/33 detected individuals (39 %) and all life-history groups. Long-term residency, lasting at least 12 months, was documented in 3/33 individuals (9 %), all of which were female. Over longer time scales, there was evidence for multiannual site fidelity.
- The prevalence and scale of residency among tagged individuals suggest that removing pressures such as fishing from areas the size of the LSSoJ MPA has the potential to benefit multiple life-history categories, especially females, over monthly and seasonal timescales.

Summary

This study investigated the fine-scale movements of flapper skate in different life-history categories (male, female, immature and mature individuals) within the LSSoJ MPA. Passive acoustic telemetry and archival (depth) data from the 2016/17 study were used to examine the movements of tagged individuals and the extent of residency around acoustic receivers (Fig. 3). Capture-recapture data were used to examine the evidence for site attachment over a longer timescale.

Of the 42 acoustically tagged skate, 33 (77%) were detected at acoustic receivers. Across all detected individuals, the number of days with detections ranged between 1–256 (median = 34) days (Fig. 4). Detections were most common in March/September 2016 immediately following the two tagging events. There was evidence of site fidelity, with seasonal patterns of detections observed for five males and five females, most detections in spring, autumn, and winter, with a gap in detections over the summer for these individuals (Fig. 4). However, four immature females (540, 249, 560 and 532) and one mature female (555) were detected throughout the study period (Fig. 5). For all individuals, detections principally concentrated at the receivers between Mull and Kerrera (in an area termed the 'southern receiver curtain' that is highlighted in red in Figs. 3–5). However, localised detections in this area may have been influenced by tagging location and do not imply a population-level preference for this area within the LSSoJ MPA.

Despite variation in detection patterns, residency within the LSSoJ acoustic array was relatively common among all life-history categories (at least for individuals >107 cm in length) and extended for periods of three months (short-term residency) to at least 15 months (long-term residency). Short-term residency was documented in 13/33 detected individuals (39%), including all life-history categories. Long-term residency was documented in 3/33 detected individuals (9%), including two immature females and one mature female. Collectively, there was evidence for short- or long-term residency around receivers in 16/33 of detected individuals (48%). Over a longer timescale, capture-recapture data indicated multi-annual site affinity in 63 % of detected individuals. However, given the number of tagged individuals and limited receiver coverage, the prevalence and spatial-temporal scale of site affinity and its drivers remain uncertain.

Nevertheless, building on previous research, the strength of site affinity revealed by the movement data analysed in this study suggests that removing pressures such as fishing from areas the size of the LSSoJ MPA has the potential to benefit multiple life-history categories, especially females, over monthly and seasonal timescales. Prolonged residency within particular areas of the acoustic array (such as the southern receiver curtain) suggests that smaller protected areas could benefit some individuals over these timescales, while larger protected areas would be expected to benefit more individuals over longer timescales. At the same time, the spatial scale of residency implies that skate may be particularly vulnerable to localised pressures, especially in areas that are disproportionately important for their life history.

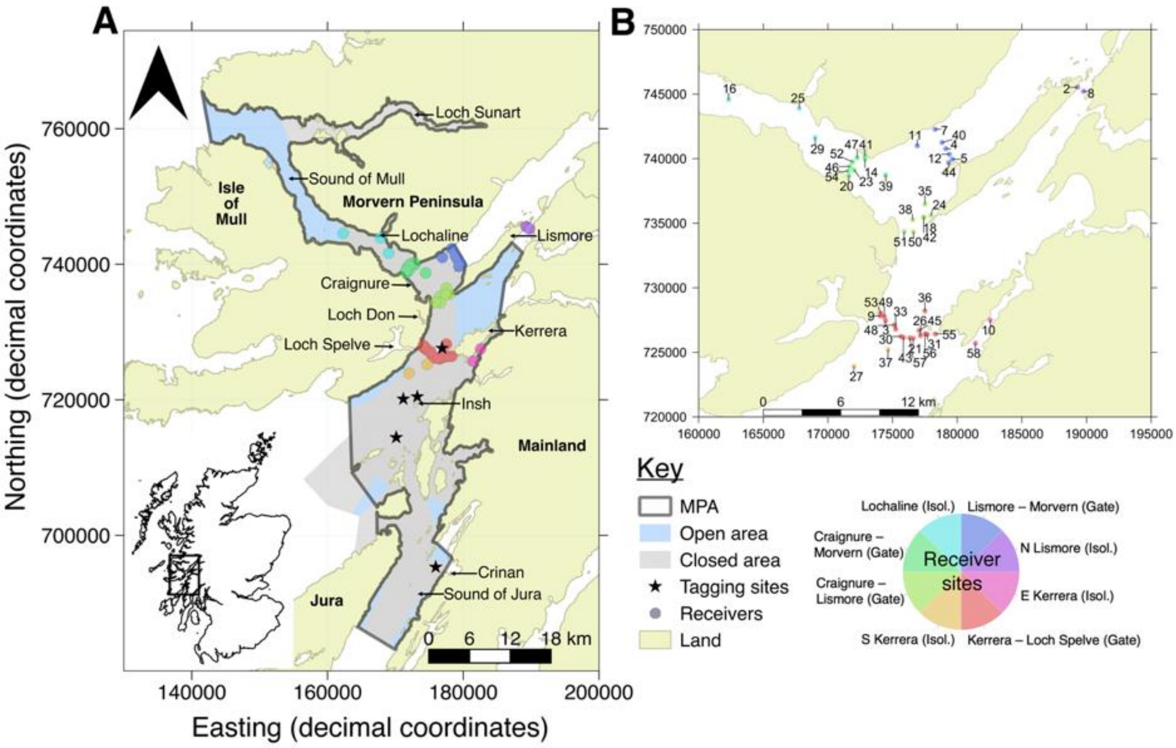

Figure 3: The study site and acoustic array. **A**, The LSSoJ MPA. The MPA's boundaries are shown in black and closed and open areas are shown in grey and blue respectively. The coloured points mark receivers. The stars mark acoustic tagging sites. **B**, The receiver array. Receivers are grouped into eight main sites by which they are coloured according to a colour wheel which relates to site location (see key). The coordinate reference system is British National Grid. Background Ordnance Survey maps © Crown copyright and database rights [2019] Ordnance Survey (100025252).

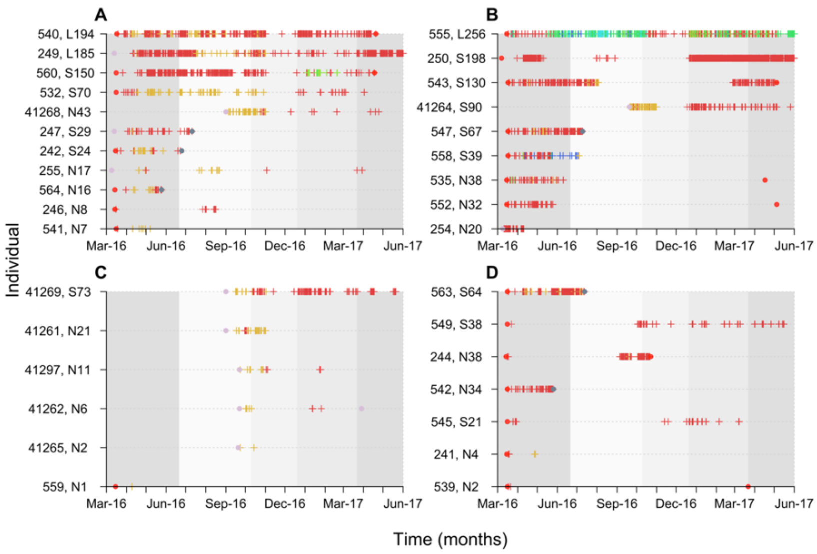

Figure 4: **Detection histories for each life-history category. A**, immature females; **B**, mature females; **C**, immature males; and **D**, mature males. Each point (+) defines the time of an acoustic detection for a particular individual. Filled points (•) mark the date of tagging and tag removal (if applicable) respectively. Point colour corresponds to receiver location (see Fig. 3), with tagging events off Insh (away from receivers) shown in pink and tag removal events in unrecorded locations shown in grey. The background colouration highlights the season. Y-axis labels define individual IDs, residency categories (N, non-resident; S, short-term resident; L, long-term resident) and the total number of days with detections (by which individuals are ordered). Short-term and long-term residents are individuals with periods of detections spaced less than 31 days apart over more than three or 12 months, respectively.

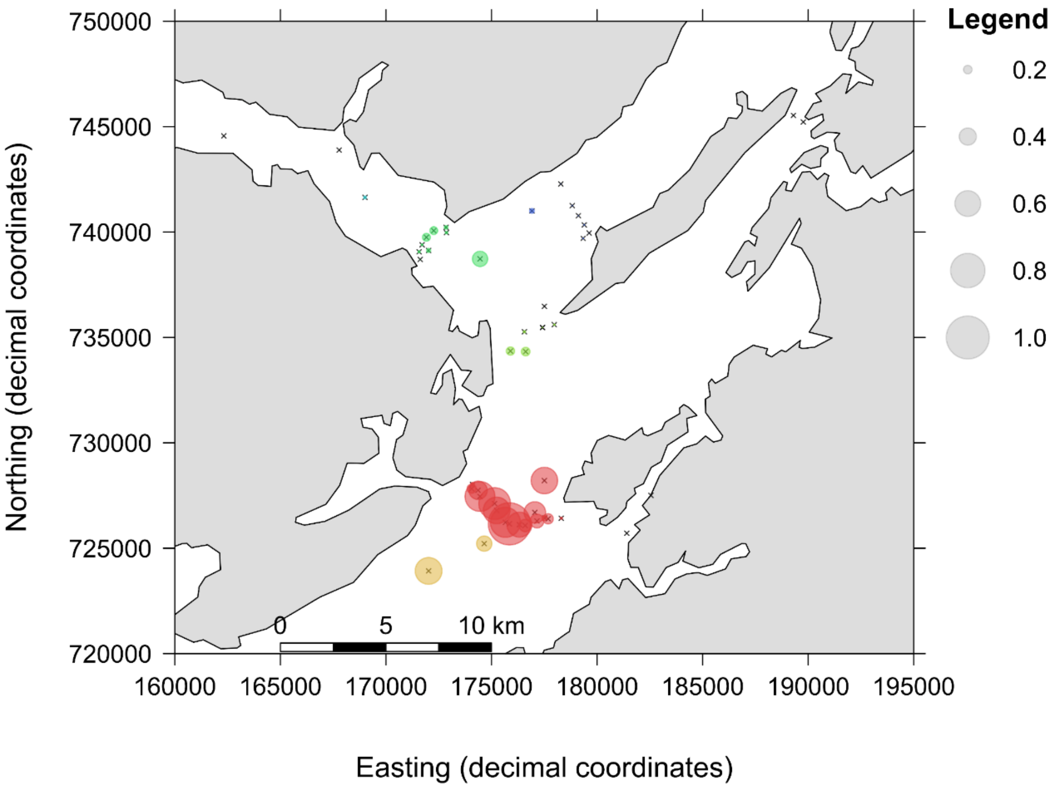

Figure 5: Pattern of acoustic detections at each receiver. The size of the circle shows the proportion of detections at each receiver during it's operational period. The colours relate to areas shown in Fig. 3.

Assess core habitat use of skate within the Loch Sunart to the Sound of Jura MPA

This section summarises (Thorburn et al., 2021)*. All figures are adapted from this paper.*

Key findings

- Skate used a total depth range of 1 to 312 m, but typically occurred between 20 and 225 m.
- There is a seasonal change in core depth use from 100 to 150 m over summer months to 25 to 75 m over winter months. This suggests high occupancy of the deep trench system by all size classes larger than 110 cm total length TL over summer.
- Larger skate tend to use a shallower depth range than smaller skate, but understanding of this relationship is limited due to a lack of data for skate <110 cm TL.

Summary

As a dorsoventrally flattened species, adapted for a benthic lifestyle, skate are generally associated with being on, or close to, the seafloor (Hunter et al., 2004), and are often found resting there (Kuhnz et al., 2019). Flapper skate have been suggested to spend prolonged periods, up to 30 h, resting on the seafloor (Wearmouth & Sims 2009) throughout the year (Wearmouth & Sims 2009; Pinto et al., 2016); thus, depth use is a good proxy for habitat use in flapper skate. Due to this, depths recorded by archival tags can be considered as being closely associated with the local bathymetric conditions.

Depth records from 25 archival (depth) tags, ranging in duration from 3 to 772 (mean = 246) days (see Table 5, pg 34 for details), were analysed; 21 from the 2016/17 study and an additional four from Neat et al., (2014) and Pinto & Spezia (2016). Depth ranges were 3 to 312 m for males and 1 to 301 m for females (Fig. 6), but skate typically used depths between 20 and 225 m. There was variation observed in depth use among individuals (Fig. 6), with some spending most of their time within a 50 m depth range, while others displayed broad depth distributions with no apparent depth preference. High usage of waters shallower than 50 m was observed in all skate larger than 135 cm TL, especially females (Fig. 6). Depth use showed a similar seasonal trend for both sexes, being shallower on average over winter and early spring and deeper over summer (Fig. 7). Individuals recorded as being in waters deeper than 290 m (the max depth in the LSSoJ MPA) must have moved outside of the LSSoJ MPA boundaries at some point. Water temperatures ranged from 6.3 to 16.37◦C (mean = 11.25); the range of temperatures suggests little variation in the water column and that the temperatures skate experience is dependent on available temperatures at depth.

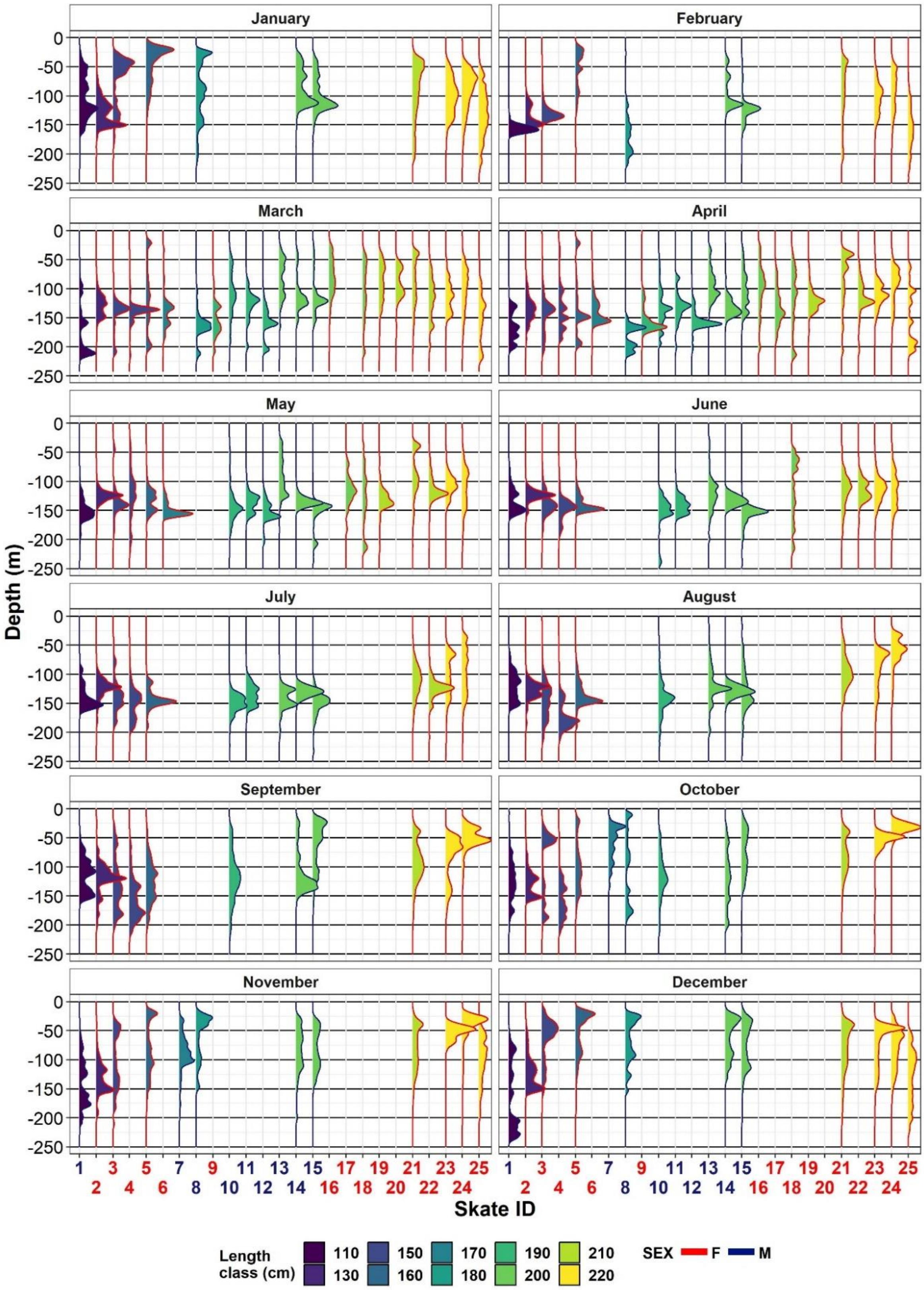

Figure 6: Individual depth distributions per calendar month. X axis shows Tag ID (staggered to ease visualisation; see Thorburn et. al., 2021 for details). Length class is colour-coded to facilitate interpretation. Sex is also colour-coded, both in the X axis label and in the distribution outline: females are outlined in red and males outlined in blue.

Seasonal and ontogenetic shifts in depth use were investigated using generalised additive mixed models (GAMMs). Both depth and temperature were modelled in relation to TL and day of year (Julian day), with individual as a random effect. To focus on trends over seasonal timescales, daily averages for depth and temperature data were used. Sex was not included in either model due to a lack of data across a suitable range of sizes for each sex, which limited our ability to separate size and sex effects. This model showed a seasonal change in depth, with deeper waters being used over summer (May–July; Fig. 7), and increasingly shallow water use over autumn and early winter (August–December; Fig. 7).

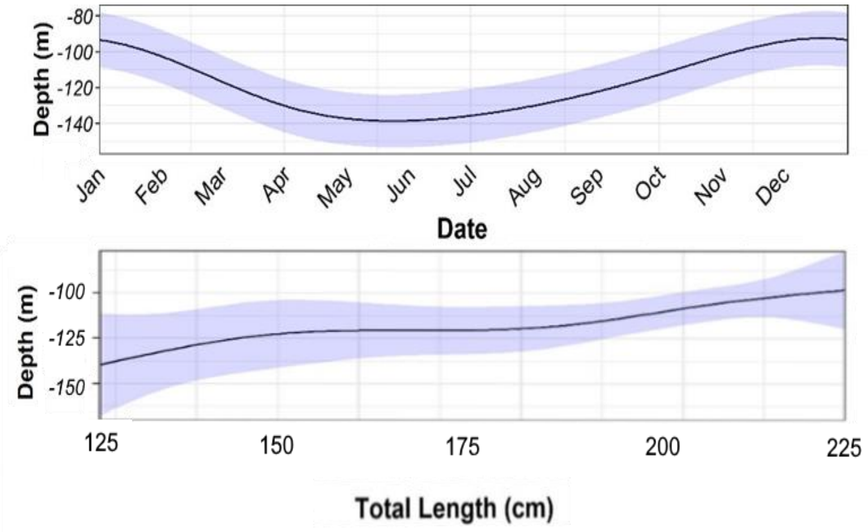

Figure 7: Generalised additive mixed model expected value predictions for depth in relation to total length and Julian day, with 95% pointwise confidence bands.

Highest density intervals were used to identify the home (95%) and core (50%) highest density depth regions (HDDRs) for each 10 cm length class (Fig. 8, Fig. 9). Home HDDRs typically occurred between 20 and 225 m (Fig 9). In line with the results from the GAMM, core HDDRs showed seasonal and ontogenetic variations with core HDDRs over summer (100–150 m) suggesting high use of the deep trenches in the region by all skate. Core HDDRs were in shallower depths over winter (25–75 m; Fig 9).

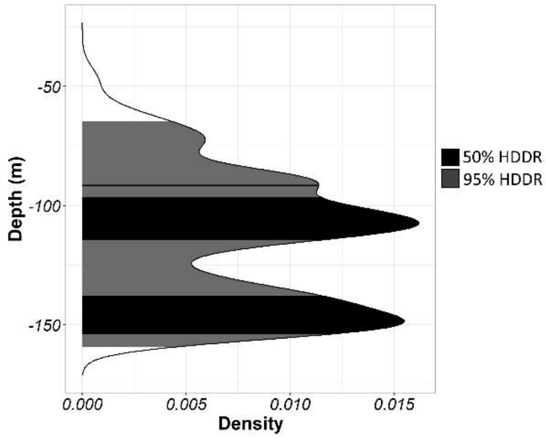

Figure 8: Example core (50%) and home (95%) highest density depth regions of a depth profile.

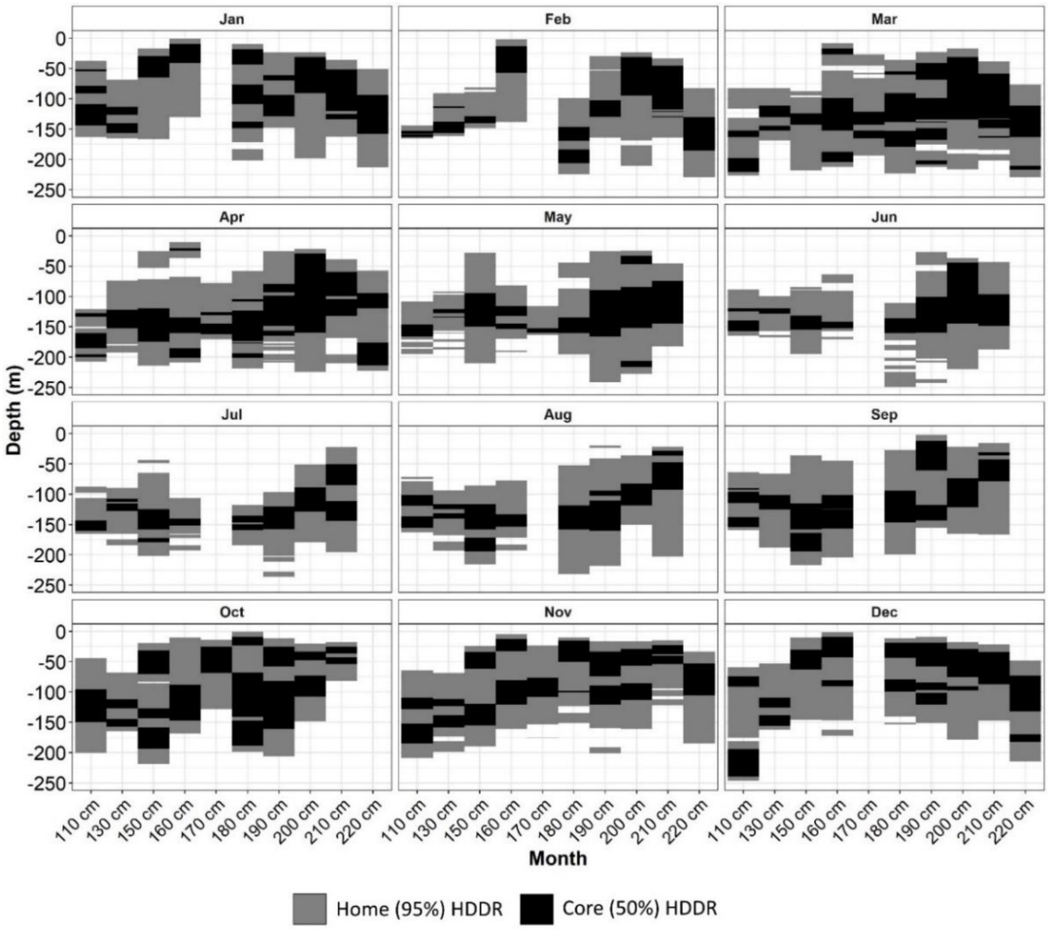

Figure 9: Home (95%) and core (50%) monthly HDDRs per 10 cm length class of skate as estimated by Highest Density Interval analysis.

The extent to which the LSSoJ MPA covers areas associated with core and home HDDRs throughout the year was investigated by identifying the areas in the region with bathymetry data that matches the HDDRs. Bathymetry data were obtained from the INIS Hydro (Ireland, Northern Ireland, and Scotland Hydrographic Survey) programme (5 m resolution) (Howe et al., 2015) and the European Marine Observation and Data Network Bathymetry portal (approximately 115 m resolution). Bathymetry data were combined (covering 94% of the LSSoJ MPA) and rounded into 1 m depth bands. For each 10 cm length class, for each month, bathymetric cells within the core and home HDDR were identified and mapped. Core and home HDDRs were mapped separately. The maps of monthly matching depths for each length class were stacked, and the number of length classes per bathymetry band was counted. This was converted into a percentage of the overall total number of length classes (Fig. 10). The area within the LSSoJ MPA with bathymetric depths associated with skate HDDRs was calculated, allowing the LSSoJ MPA's coverage of areas associated with HDDRs to be assessed. This was calculated as a percentage value, plotted as a radar plot (Fig 11).

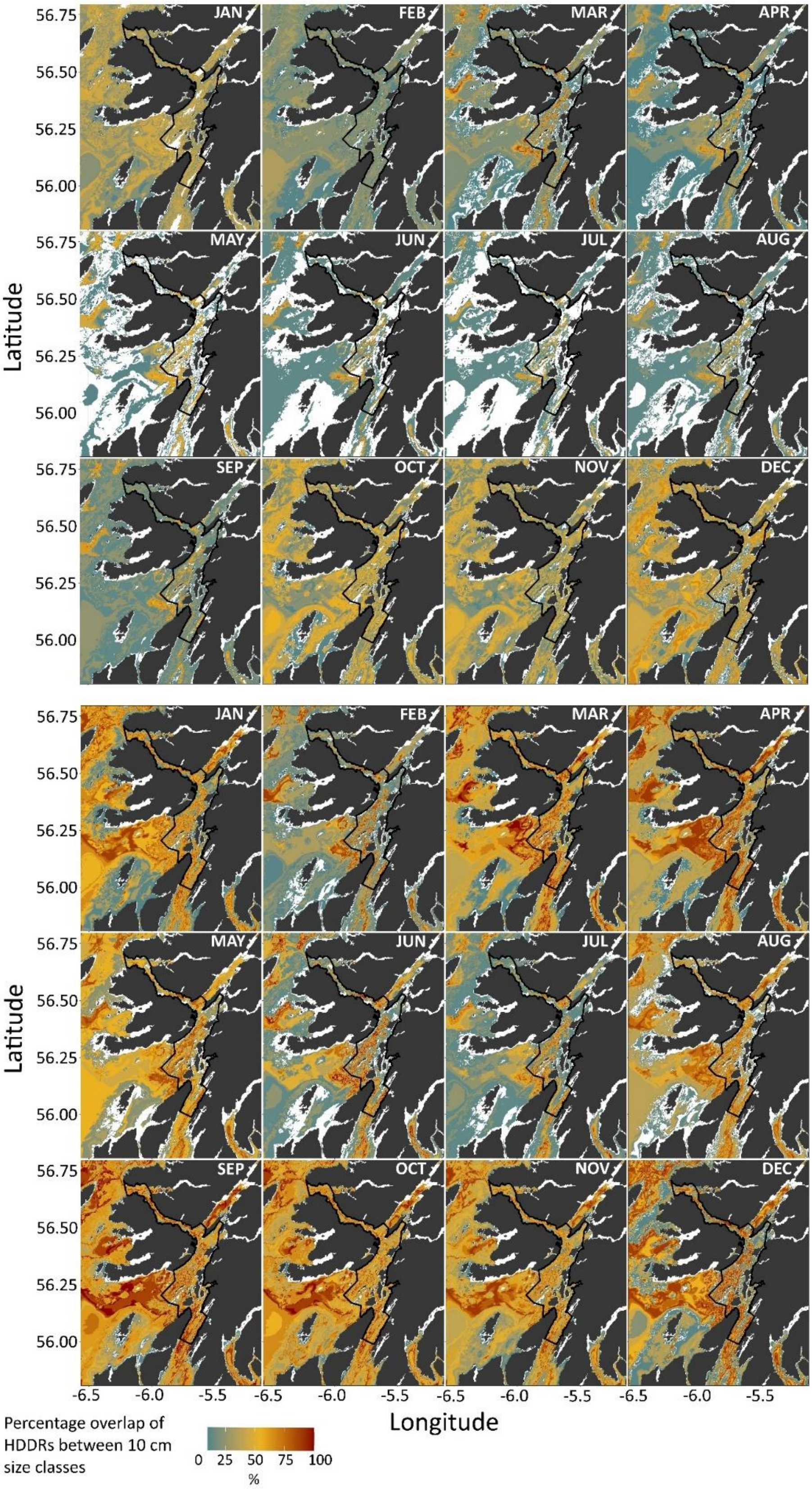

Figure 10: Areas within the Loch Sunart to the Sound of Jura Marine Protected Area management area and surrounding region with depths associated with core (top) and home (bottom) Highest Density Depth Ranges for each 10 cm size class. Colour (based on the colour scale bar) reflects the percentage of size classes whose HDDRs includes the depth value in each cell.

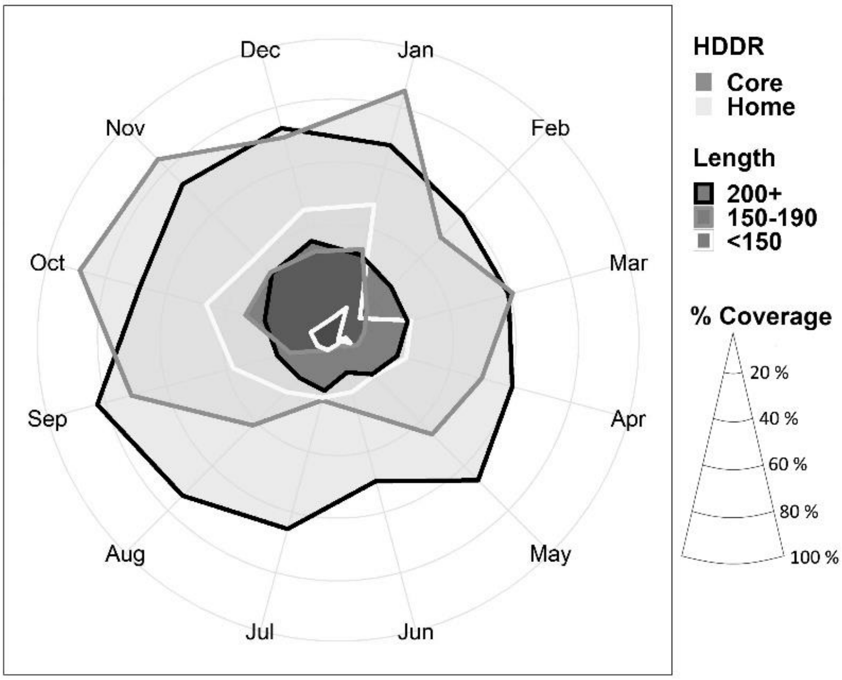

Figure 11: Percentage of the Marine Protected Area of areas associated with home and core HDDRs. Length classes grouped into three groups to assist visualisation.

The locations associated with skate HDDRs were widespread throughout the region between September and April for most length classes (Fig 10). From March to September, the core HDDR for most length classes was restricted to deeper waters associated with the trench systems throughout the area (Fig. 10). There was seasonal variation in the proportion of the LSSoJ MPA covering both core and home HDDRs which was higher from August–January (Fig. 11, Tables 1 and 2). There was notable variation between size classes, with the LSSoJ MPA covering more areas associated with HDDRs for larger skate (mature females >200 cm TL) (Fig. 11).

Table 1: The percentage area of the LSSoJ MPA for which we have bathymetric data (717 km^2) that matches the core (50%) Highest Density Depth Regions (HDDRs) for each 10 cm TL class per month.

TL (CM)	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
	50% HDDR											
110	19.9	1.7	3.7	6.6	3.6	5.4	3.4	10.4	11.7	16.9	11.9	11.2
130	7.7	4.7	7.8	7.8	2.6	2.9	5.7	5.1	8.2	7.5	8.2	9.2
150	36.1	3.3	3.8	9.7	8.7	4.9	8.3	7.9	11.0	36.1	36.1	34.0
160	33.5	47.5	27.6	12.1	7.3	2.3	2.3	4.6	15.4	19.7	37.9	40.9
170			8.5	5.0	1.4					44.5	14.6	0.0
180	48.6	7.0	7.9	10.1	5.7	5.1	4.6	10.3	16.7	24.7	41.0	41.0
190	14.1	6.6	10.8	10.5	7.2	6.0	6.6	7.8	32.5	43.6	38.6	45.6
200	47.8	49.6	41.3	38.9	24.2	15.5	14.8	14.7	20.6	32.4	42.9	47.5
210	26.5	20.6	23.1	16.0	12.8	12.2	24.9	25.9	25.7	22.3	25.7	33.9
220	19.3	11.0	13.8	13.3							30.4	25.8

Table 2: The percentage area of the LSSoJ MPA for which we have bathymetric data (717 km^2) that matches the home (95%) Highest Density Depth Regions (HDDRs) for each 10 cm TL class per month

TL	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
(CM)	**95% HDDR**											
110	61.5	4.3	27.8	16.1	18.2	23.0	20.1	29.6	36.4	58.7	42.7	46.3
130	34.2	21.5	26.7	35.1	20.4	17.5	24.3	23.4	39.2	34.7	37.8	45.8
150	87.1	22.0	24.4	47.9	67.3	27.3	38.4	27.4	56.5	80.6	83.8	87.3
160	85.8	87.9	90.9	68.8	27.7	29.9	17.7	31.2	59.1	91.7	92.2	91.6
170			66.9	29.8	12.2					81.3	79.1	0.0
180	95.0	25.1	47.6	40.9	48.6	17.9	15.1	53.0	80.9	95.9	85.2	86.3
190	73.7	62.8	74.6	65.4	72.3	31.2	20.9	55.0	89.3	93.1	82.6	84.9
200	86.1	85.8	84.6	81.2	81.8	54.5	49.6	61.6	83.4	81.1	86.7	89.1
210	62.2	59.4	58.0	52.2	51.0	45.0	81.4	85.1	82.2	56.2	63.2	74.1
220	54.1	32.8	36.1	48.6							70.3	55.9

These results suggest that flapper skate are not solely associated with deep water as, especially large females, are frequently found in shallow waters. The current management, which protects the entire depth range, is appropriate for the protection of flapper skate throughout much of its life history. This research demonstrates why collecting data across seasonal scales and multiple ontogenetic stages is needed to assess the effectiveness of spatial management. However, there are areas of deeper water to the south of the LSSoJ MPA in the Firth Lorn and the Sound of Jura that correspond to the skate's core depth range over summer that warrants further investigation with regards to fisheries interactions. These areas could be considered in any future LSSoJ MPA boundary revisions.

Vertical movements

This section summarises (Lavender et al., 2021a)*. All figures are adapted from this paper.*

Key findings

- The vertical movements of tagged flapper skate exhibited distinct short- and long-term patterns, including irregular diel cycles, prolonged periods of low and high vertical activity, repeated movements around a central depth and seasonality.
- Alongside individual variation, there was evidence for associations between vertical movement and environmental cycles.
- In winter, there was clear evidence for diel cycles in vertical movement, with nocturnal movements into shallower water (normal diel vertical migration) and elevated nocturnal activity. These patterns broke down in summer, when individuals were less active and spent more time in deeper water.

Summary

The vertical movements of 21 flapper skate were investigated using the 2016/17 archival depth data collected at two-minute intervals from tagged individuals. Depth records comprised nearly four million observations and included eight time series longer than one year. Additive modelling and functional data analysis were used to investigate vertical movements in relation to environmental cycles and individual characteristics.

Vertical activity was generally low (median = 0.004 ms^{-1}) but ranged from 0.00–1.13 ms^{-1}. Over seasonal timescales, individuals exhibited marked variation in vertical movement. Almost all individuals ranged extensively in depth (Figs. 6 & 12) but most also used narrow depth ranges over prolonged periods lasting from weeks to months (Figs. 6 & 12). There was clear evidence for repeated movements to/from a narrow range of depths. Repetition was most noticeable over daily–weekly timescales and lasted for prolonged periods in nine individuals (Fig. 12). In general, vertical movement was more restricted in spring and summer, when individuals tended to use deeper water, compared to autumn and winter, when higher vertical movement was associated with increased use of shallower water (Fig. 12). Over shorter timescales, individual time series were extremely variable, with periods of relative stasis, sometimes lasting more than one week, punctuated by high vertical activity (Fig. 12). For most individuals, there were times when vertical movement coincided with diel cycles, but this pattern appeared to be irregular through time and varied within and among individuals (Fig. 12).

Despite considerable variation in vertical movement within and among individuals, flexible regression indicated associations between vertical movement and environmental cycles. A diel–seasonal structure in vertical movements was strongest. In autumn and winter, there was clear evidence for diel vertical movement patterns, with daytime depths on average 75 m deeper and reduced vertical activity than at night (i.e., diel vertical migration, DVM). However, this pattern weakened in summer when skate tended to be less active and spend more time in deeper water. The drivers of these patterns are uncertain but foraging or the avoidance of unfavourable near-surface conditions, such as high light levels, are the most plausible explanations.

The study of vertical movement has implications for skate management. Most bycatch occurs in bottom trawls with a relatively low headline. The benthic habit of skate makes them particularly vulnerable to this gear, but vertical movements will substantially affect their exposure and catchability. The results of this study suggest skate are more likely to be caught in bottom trawls over the summer when vertical activity is lower. If higher activity is associated with movement off the seabed, the vulnerability of skate to bottom trawling in autumn and winter may be lower. An important development of this work is to determine if vertical activity is associated with movement of the seafloor or not as this may have fisheries management implications with regards to setting seasonal restrictions on gear type in key areas for skate.

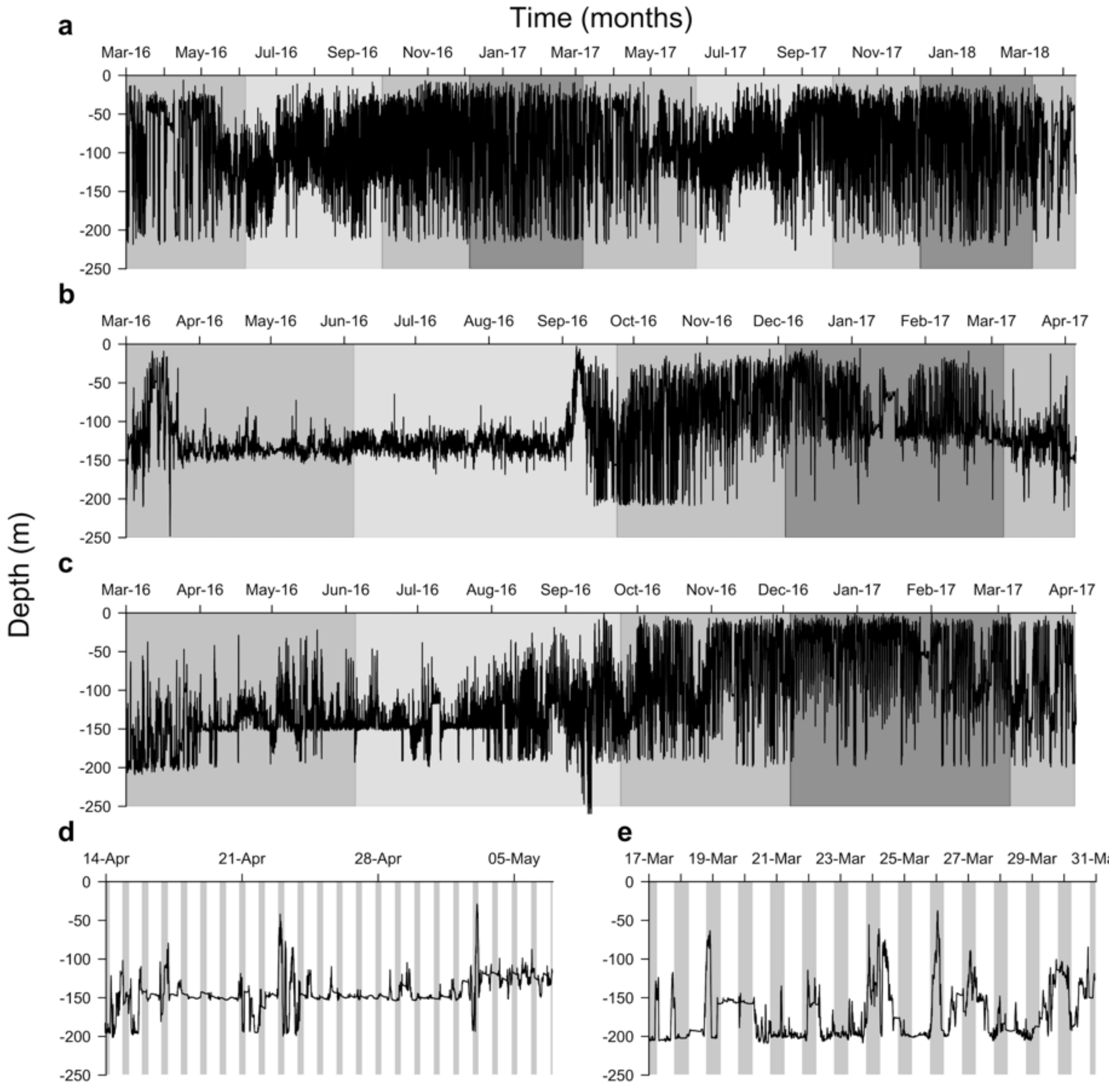

Figure 12: Example vertical movement time series for **a**, 1547; **b**, 1548; **c**, 1522; **d**, 1533; and **e**, 1574. **a–d** illustrate distinct long-term patterns, including high vertical activity, prolonged periods of low activity, repeated movements around a central depth and seasonality. Background shading distinguishes seasons. **d–e** illustrate short-term patterns, including (**d**) periods of stasis interspersed with high vertical activity and (**e**) irregular diel cycles. Background shading distinguishes day (light) from night (dark).

Initial findings into flapper skate resting behaviour

This work is subject to ongoing analysis and so the results presented here represent an initial summary that is subject to further development.

Key findings

- Some flapper skate spend a large amount of time resting on the seafloor, up to 87.5% of time.
- Flapper skate appear to rest more between February–August.
- When skate rest, they will be vulnerable to different types of fishing gear than when they are actively moving. The modified mobile gear requirements in the LSSoJ MPA may be more effective at mitigating the capture of resting skate.
- Resting behaviour is more prevalent February – August and appears to take place in relatively narrow depth ranges compared to overall depth use.
- Resting depths appear to vary between males and females, this is most noticeable over winter August–February. Females display a high level of seasonal variation in the depths used for resting, being deeper over summer and shallower over winter. Seasonality is less apparent in males, although resting behaviour occurs at a wider range of depths over winter.

Summary

One management measure in the LSSoJ MPA is the prohibition of dredging and trawling with a tickler chain (Fig. 2). The removal of the tickler chain, which has been shown to reduce bycatch of skate (Kynoch et al., 2015), may be most effective for skate that are resting on the seafloor as they may avoid capture if the rubber rock-hopper discs fitted to the bottom of the trawl pass right over the top of them (McIntyre et al., 2015). This gear modification can result in up to 50% escape rates, depending on the species. Therefore, understanding the resting behaviour of flapper skate in the LSSoJ MPA is important in terms of evaluating management measures.

Flapper skate have been shown to spend prolonged periods of up to 30h resting on the seafloor throughout the year (Pinto et al., 2016; Wearmouth & Sims 2009). Resting behaviour can be identified from tidal traces in archival depth data. In this study, using the 2016/17 archival depth data, the difference in depth between successive observations for each individual was calculated and periods of resting were defined as times when the successive change in depth was <0.24 m for at least 30 minutes. The threshold value was determined by the maximum step change observed in visualised tidal patterns in the data.

This showed that resting occurs throughout the year, but there is a seasonal pattern to the resting behaviour, with time spent resting increasing between February and August (up to 87.5% of the time resting; Fig. 13).

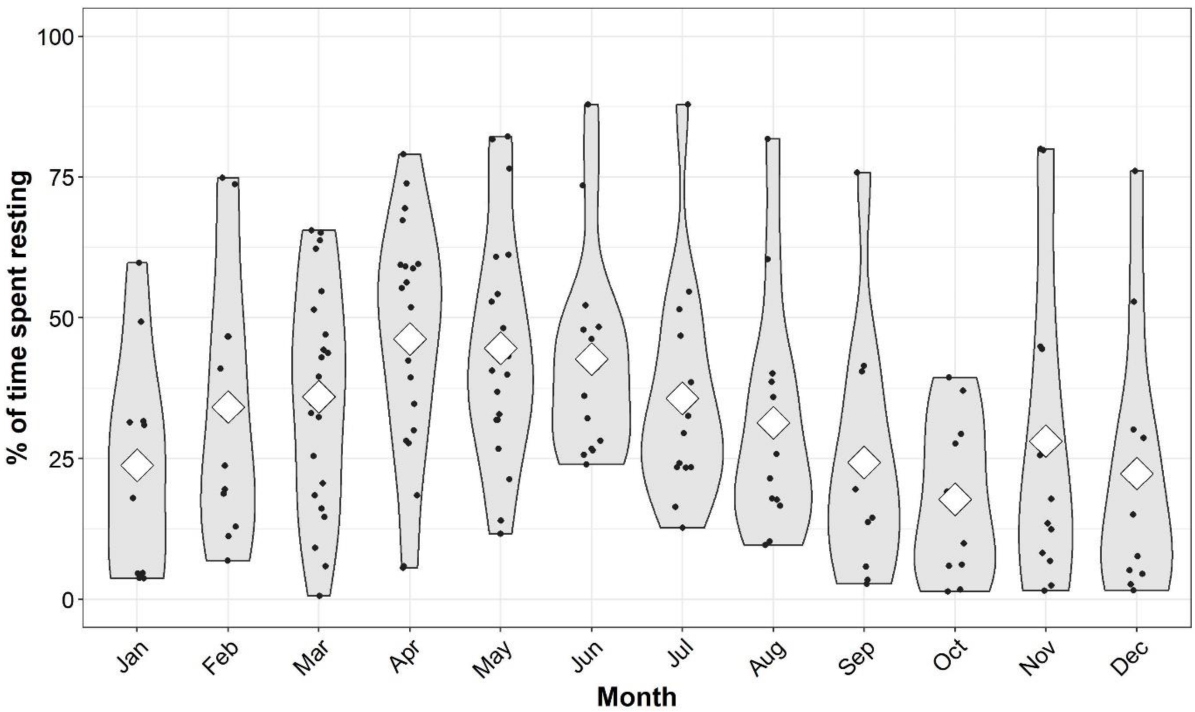

Figure 13: Percentage of time series spent in 'resting behaviour' across all archival records per calendar month, visualised as a violin plot. White diamond shows mean value, black points show the percentage of time spent resting for each individual, with a jitter function to prevent overlap.

In line with the observed seasonal changes in depth use (Figs. 6, 7 & 12), there was a large amount of seasonal variation in the depths used for resting (Fig. 14). This was most noticeable in females, with most resting behaviour occurring below 100 m in Mar–Jul, when resting in shallower water began to increase and remained high over winter. Males spent more time resting in deeper water (>200 m), and there was less seasonal variation than females (Fig. 14). However, males spread their resting behaviour more evenly across a range of depths from Oct–Jan (Fig. 14).

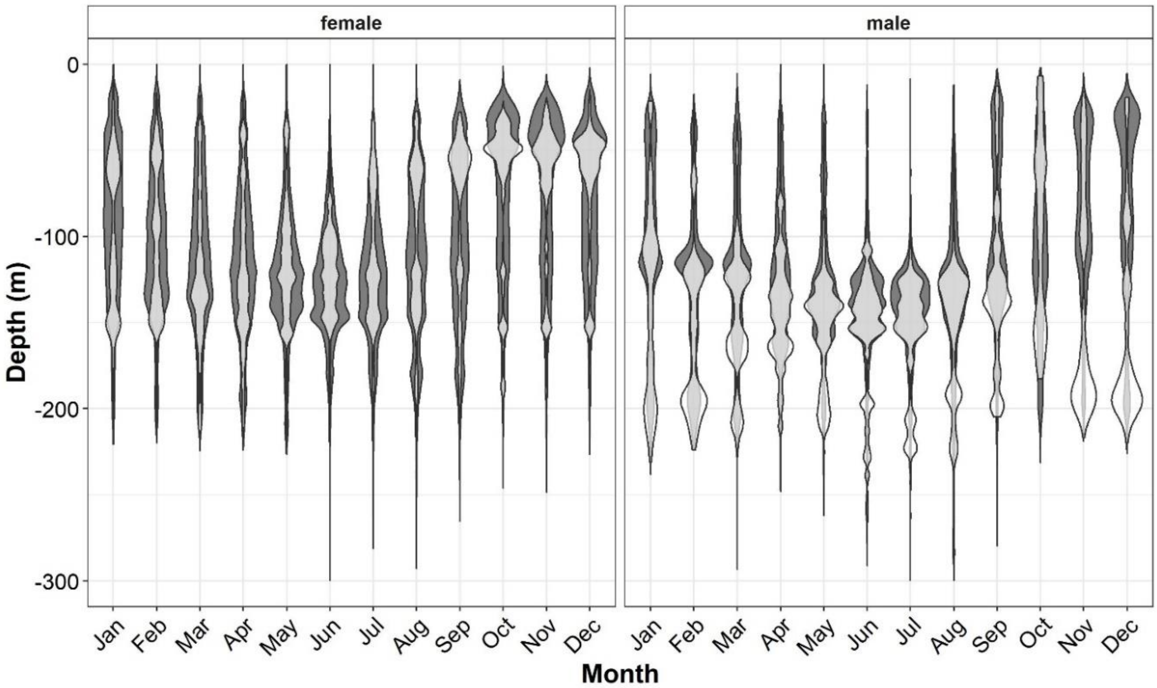

Figure 14: Distribtuion of 'resting' vs 'active' behaviour compared to depth for each archival record, per calendar month for males and females. Resting behaviour is light grey, active behaviour is dark grey.

These results suggest that the removal of the tickler chain as a tool for mitigating skate bycatch may be most effective between April and June for skate due to the increased amount of resting behaviour observed at this time of year. This measure may also be more effective at different depths throughout the year, especially for females. The shift in the seasonal distribution of resting depths may also influence the level of interaction skate have with fishing activity throughout the year.

While skate resting on the seafloor may be less vulnerable to bottom and demersal trawling, as the net may pass over them, than skate actively swimming, there is a possibility that resting skate may be at increased risk from dredging activity, as dredges are less likley to pass over resting skate. More research on the impact of dredging on different life-history stages of flapper skate would improve our understanding of interactions between dredging and flapper skate.

Initial findings into the flapper skates reproductive cycles

This work is subject to ongoing analysis and so the results presented here represent an initial summary that is subject to further development.

Key findings

- Mature females carrying eggs were found in the LSSoJ MPA using ultrasound imaging.
- Ovarian follicle size, presence of eggs, and hormone cycles suggest egg-laying may occur between August and April, but wider sampling is needed to confirm this hypothesis.
- The levels of hormones evidence suggest sizes of maturity >180 cm TL for females and >170 cm for males.
- Small juvenile skate (<40 cm TL) presence has been confirmed within the LSSoJ MPA.

Summary

There are no visual diagnostics to determine the reproductive state of female skate, and this is commonly determined via post-mortem investigations. In skate species, the fully formed egg case is held in the uterus for a period of time, up to several days, to harden (Koob & Hamlett 1998); identification of an egg in the uterus would prove the female to be in an egg laying phase. Recent technological advancements in ultrasound equipment have meant that the use of portable units at sea is feasible. Sonographic images have been shown to be capable of imaging and determining the size of ovarian follicles in both oviparous and viviparous species of elasmobranch (Daly et al., 2007; Whittamore et al., 2010) and have been used to identify the presence of egg capsules in oviparous (Whittamore et al., 2010) and ovoviviparous (Carrier et al., 2003) species.

Elasmobranchs reproduction appears to be controlled by the same steroid hormones as other vertebrates with the female ovary producing three major gonadol steroids: 17β-estradiol (E), testosterone (T) and progesterone (P) (Koob & Callard 1999; Gelsleichter 2004). In both oviparous and viviparous species:

- Levels of E peak during follicular development.
- Once the ovulatory period is complete E levels reduce and there is a rise in P.
- P rises briefly before ovulation, then remains relatively low during encapsulation, retention and oviposition.
- During oviposition, E levels appear to decrease, and T levels rise (Rasmussen & Murru 1992).

Changes in the levels of these hormones are also related to the maturation process in elasmobranchs:

- Levels of E peak during follicular development.
- Once the ovulatory period is complete E levels reduce and there is a rise in P.
- P rises briefly before ovulation, then remains relatively low during encapsulation, retention and oviposition.
- During oviposition, E levels appear to decrease, and T levels rise (Rasmussen & Murru 1992).

By measuring the levels of each hormone, it is possible to investigate the reproductive cycle (though it is important to take individual variation into account) and, by comparing hormone levels against the body size of the skate, maturation sizes.

During tagging, ultrasound imaging was used opportunistically to assess the size of ovarian follicles and identify the presence of egg cases through visualisation of the mature ova and encasement. Blood samples were taken for analysis of T, E and P.

Ultrasound imaging

Images were captured with an associated 10 mm reference grid. It was not possible to scan every skate dorsally and ventrally and, in some cases, only brief scanning was possible. Each image was assessed for the presence and size of either ovarian follicles or mature ova. These were identified as visible ellipses. Ellipse area (mm^2) was estimated as

$$area = \left(\frac{h}{2}\right) * \left(\frac{w}{2}\right) * \pi$$

where *h* is the height (mm) of the ellipse, and *w* is the diameter (mm). Where possible, the height and length of the egg capsule was also measured, but capsule area was not estimated.

A total of 15 ultrasound images were obtained from female flapper skate of total length 178–228 cm in August 2018, April, August and November 2019, and March 2020. Of these, ovarian follicles were visible in 14, including the two smallest individuals (178 and 179 cm TL). Ovarian follicles ranged from 7 mm^2 (3 x 3 mm) to 691 mm^2 (40 x 22 mm), and there appeared to be some seasonal variation (Fig. 15). Fully developed eggs were observed in 4 skate (Fig. 16).

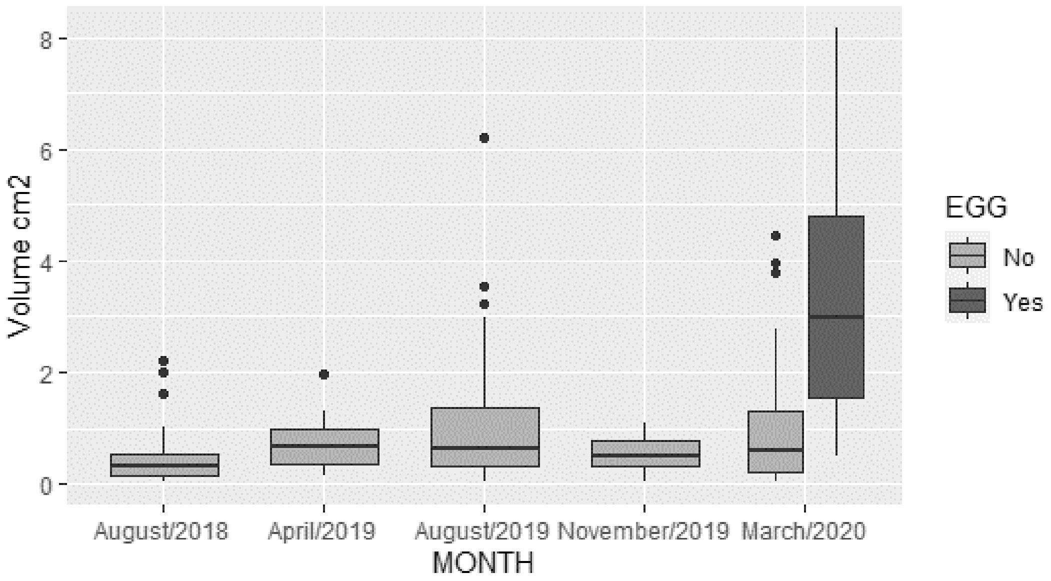

Figure 15: Maximum areas of ovarian follicle and yolk sacs in encapsulated eggs as measured from ultrasound imaging of female skate ovaries and uterus.

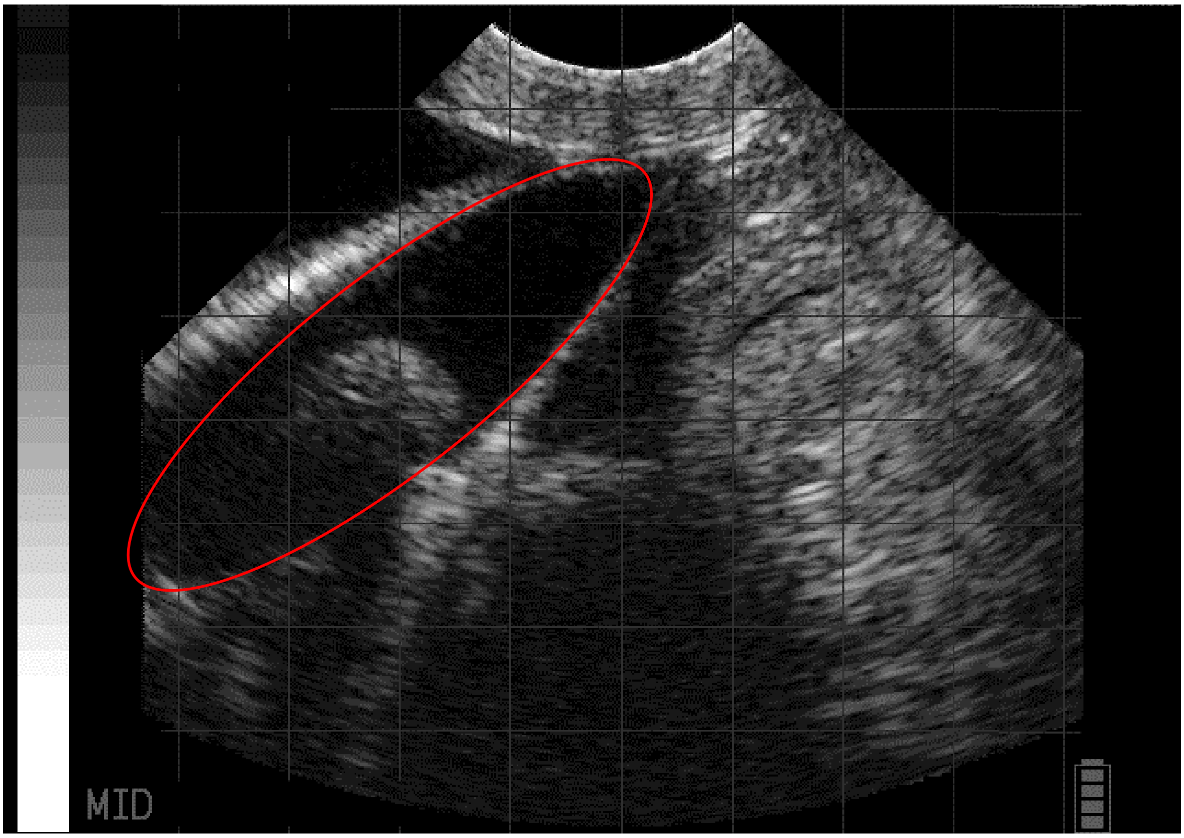

Figure 16: Ultrasound image of an egg case observed in the uterus of a female flapper skate. The red border shows the extent of the encapsulated egg with the yolk visible in the centre.

The putative seasonal variation observed egg presence (in March) and in the ovarian follicle size (which was largest in August 2019) suggests that females may be reproductively active in August and March. A lack of seasonal data prevents the full comparison of follicles throughout the year.

Blood hormones

Blood samples were analysed by the University of Edinburgh.

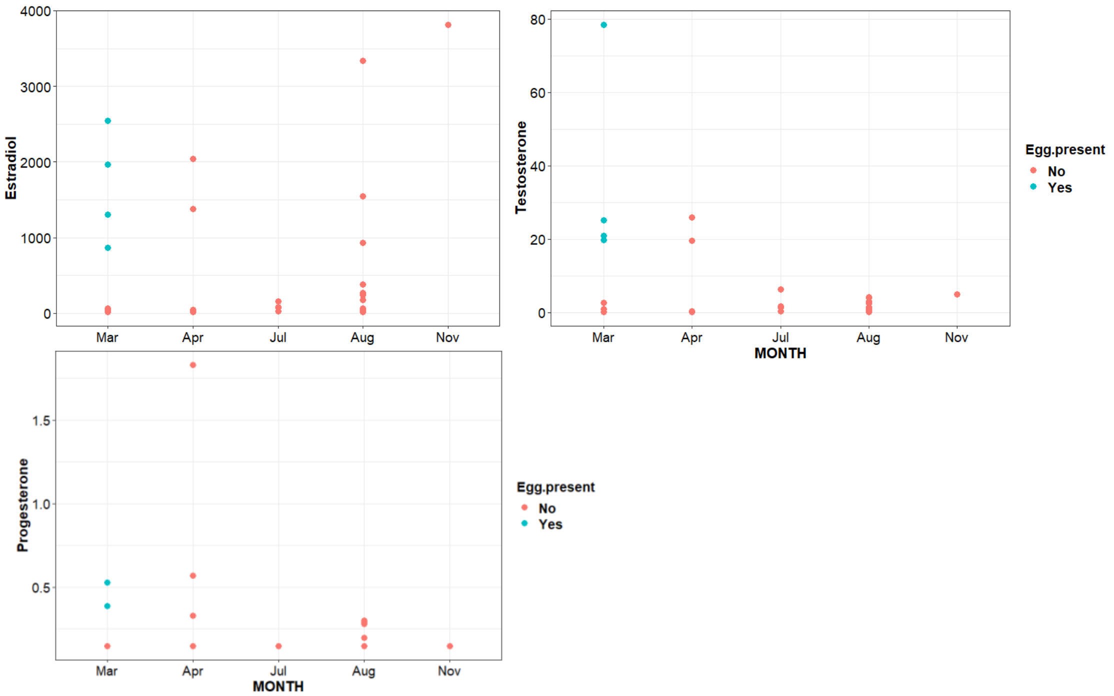

Figure 17: Estradiol (pg/ml), Progesterone (ng/ml), and Testosterone (ng/ml) levels for female skate per calendar month sampled. Colour of points shows if eggs were observed in ultrasound images

The hormone cycles in the females suggest that ovarian follicle development starts in late summer based on high levels of E. Ovulation occurs over winter with high levels of E observed in August, November and March, and oviposition is suggested to occur (at least) in spring by high levels of P and T at this time (Fig. 17). The low levels of all reproductive hormones in July suggest that female skate are not reproductively active in early summer, but as this is based on low numbers of samples, further sampling is required to substantiate this hypothesis.

Reproductive cycle results

While the numbers of samples are low with a limited temporal spread, taken together, the blood hormone and ultrasound data suggest that the egg-laying season for flapper skate is over the winter and spring months, coinciding with their increased use of shallower waters. This would benefit significantly from further sampling, with more individuals sampled throughout the year.

The presence of mature females carrying eggs suggests that there may be egg-laying grounds within the LSSoJ MPA; this hypothesis is supported by diver records of egg cases on the seafloor. The presence of two small juvenile skate was confirmed in the LSSoJ MPA by a Marine Scotland research cruise and a MEFS/MARPAMM AUV survey (Fig. 18). While numbers are low (n=2), this shows that this life stage is present the LSSoJ MPA. The low numbers of observations associate small juvenile skate with soft sediments in water 60 – 150 m deep. However, more data is required to investigate the habitat preference of small juvenile skate.

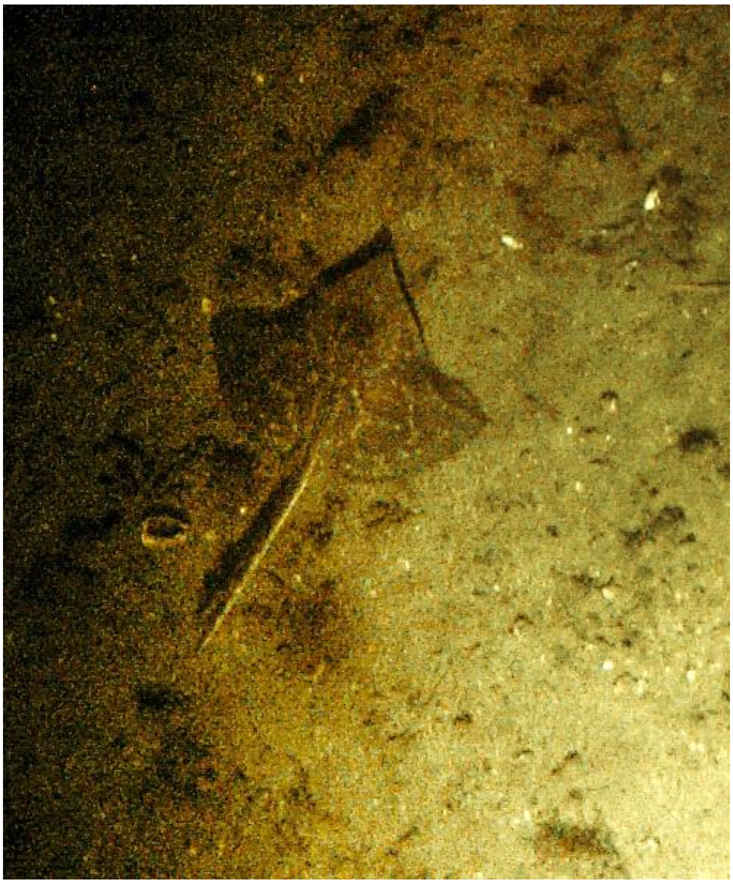

Figure 18: Picture of a juvenile skate imaged from the AUV survey within the LSSoJ MPA. Estimated size is 30-35 cm TL.

Maturity

The L50% maturity for flapper skate has been estimated as 185.5 and 197.5 cm (males/females) (Iglésias et al., 2010). Testosterone, estradiol and progesterone can also be used as an indicator for sexual maturation status in elasmobranchs (Awruch, 2013; Gelsleichter, 2004; Rasmussen & Murru, 1992).

- In male elasmobranchs, testosterone is the only hormone to be consistently associated with growth and age (Awruch et al., 2008; J. Gelsleichter et al., 2002; Rasmussen & Gruber, 1993; Rasmussen et al., 1992; Tricas et al., 2000).
- In females, estradiol appears to increase throughout maturation (Awruch et al., 2008; Rasmussen & Gruber, 1993). Levels of progesterone and testosterone also increase

throughout maturation, but in some species, they decrease once the individual has reached maturity (Rasmussen & Gruber 1993).

Hormone levels for each sex were related to total length. In females, estradiol was higher in skate 208 cm TL or larger; testosterone levels were higher in skate 211 cm TL or larger; progesterone was higher in skate 211 cm and larger, but one individual showed an elevated level of progesterone at 180 cm TL. This suggests that some female skate larger than 200 cm were mature. However, not all female skate >200 cm TL showed elevated hormone levels. The high level of variability in the hormone levels seen in females skate of mature size may be attributable to sampled skate being at different stages of their reproductive cycle. This could be due to skate laying eggs throughout the year, with individual females laying eggs at different times, or, possibly, females only producing eggs every other year as has previously been suggested (Little, 1995), although it seems unlikely in an oviparous species.

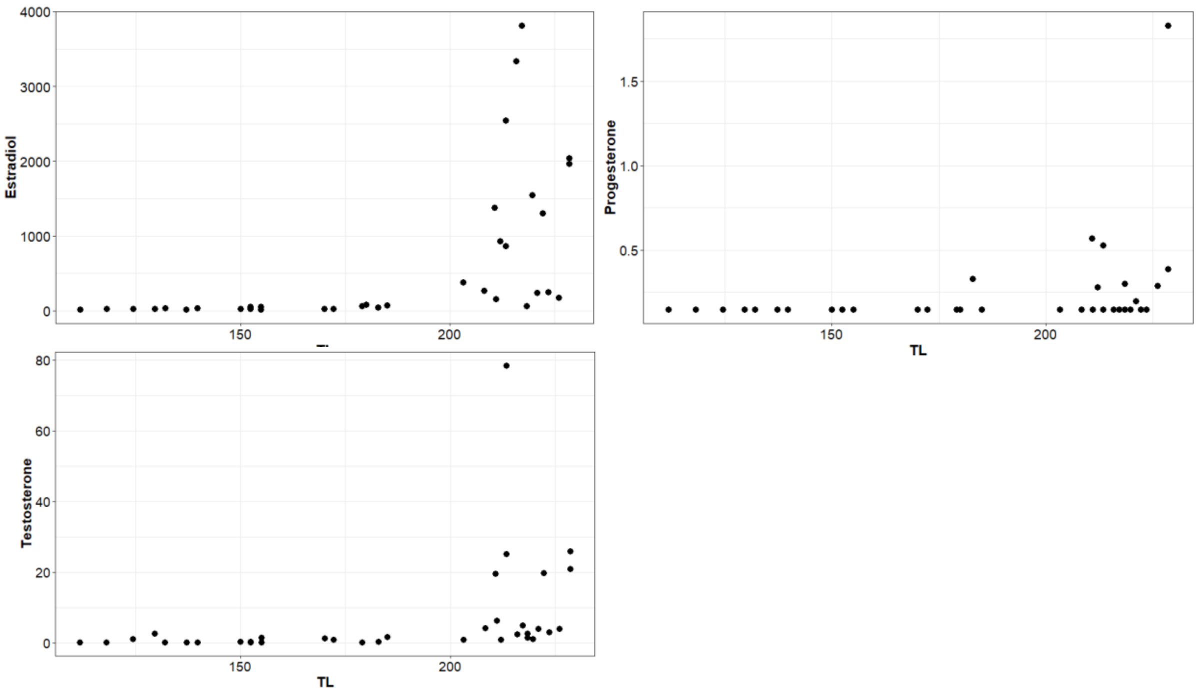

Figure 19: Estradiol (pg/ml), Progesterone (ng/ml), and Testosterone (ng/ml) levels for female skate compared to total length (cm).

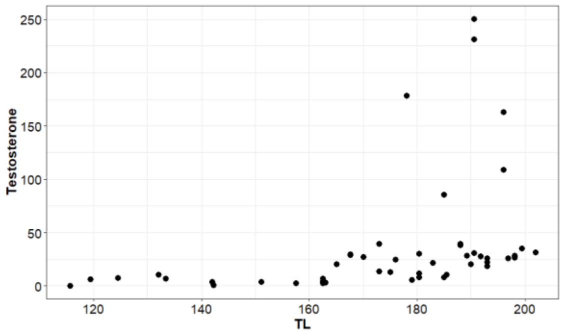

Figure 20: Testosterone levels (ng/ml) for male skate compared to total length (cm).

Set up long term monitoring array

Key findings

- MEFS has set up an acoustic array that has been collecting data since August 2018. This array will continue to monitor habitat use in the LSSoJ MPA via the SeaMonitor project.
- Sixty-one skate were tagged in the LSSoJ MPA with long-term (10 year) acoustic transmitters. These transmitters are compatible with receivers used in other acoustic telemetry projects (e.g. SeaMonitor, COMPASS and Atlantic Salmon Trust).
- Responsibility of the receivers in the LSSoJ MPA will be transferred to SeaMonitor post MEFS.

Summary

Tagging work was undertaken in collaboration with the Royal Zoological Society of Scotland, Edinburgh Zoo. All skate were caught using rod and line from a charter vessel. The sex (male, M; female, F) of each skate was recorded, and TL and disc width (DW) were measured. Skate had an acoustic tag (Vemco V16, V13, V9 or V7) inserted into the peritoneal cavity. All skate were released at their capture site within the LSSoJ MPA. All tagging work was carried out under a UK Home Office Animals (Scientific Procedures) Project Licence by licenced personnel. A total of 61 skate were tagged under the MEFS project; 22 females (132–229 cm TL) and 39 males (112–201 cm TL) (Table 3).

A passive acoustic telemetry array comprising 10 Vemco VR2AR receivers was deployed in March 2018 in the LSSoJ MPA (Table 4; Fig 21). Receivers were deployed within a RS Aqua LARC Long rope canister to facilitate full recovery. The canister was attached to 75 kg ballast using a 5 m long leash made of 18 mm sea steel. Due to covid restrictions on field work, the array was reduced to 5 receivers in 2020 for 6 months.

Table 3: Skate tagged within the LSSoJ MPA under the MEFS project (2018 onwards)

Year	Sex	TL (cm)	Location	Date	Sex	TL (cm)	Location
2018	M	162	Firth of Lorn	**2020**	M	189	Firth of Lorn
2018	M	168	Firth of Lorn	**2020**	M	192	Firth of Lorn
2018	M	151	Firth of Lorn	**2020**	M	183	Firth of Lorn
2018	M	191	Firth of Lorn	**2020**	M	198	Firth of Lorn
2018	F	226	Firth of Lorn	**2020**	F	222	Firth of Lorn
2018	M	202	Firth of Lorn	**2020**	M	198	Firth of Lorn
2018	F	218	Firth of Lorn	**2020**	M	116	Firth of Lorn
2018	M	163	Firth of Lorn	**2020**	F	179	Firth of Lorn
2018	M	199	Firth of Lorn	**2020**	F	132	Firth of Lorn
2018	M	188	Firth of Lorn	**2021**	F	150	Firth of Lorn
2019	F	137	Firth of Lorn	**2021**	M	196	Firth of Lorn
2019	M	173	Firth of Lorn	**2021**	M	185	Firth of Lorn
2019	F	229	Firth of Lorn	**2021**	M	112	Firth of Lorn
2019	F	211	Firth of Lorn	**2021**	M	175	Firth of Lorn
2019	F	183	Firth of Lorn	**2021**	M	173	Firth of Lorn
2019	M	180	Firth of Lorn	**2021**	M	191	Firth of Lorn
2019	F	155	Firth of Lorn	**2021**	M	155	Firth of Lorn
2019	M	187	Firth of Lorn	**2021**	F	180	Firth of Lorn
2019	F	152	Firth of Lorn	**2021**	M	173	Firth of Lorn
2019	F	208	Firth of Lorn	**2021**	F	211	Firth of Lorn
2019	M	142	Firth of Lorn	**2021**	M	157	Firth of Lorn
2019	F	159	Firth of Lorn	**2021**	M	170	Firth of Lorn
2019	F	216	Loch Aline	**2021**	M	178	Firth of Lorn
2019	M	197	Firth of Lorn	**2021**	M	132	Firth of Lorn
2019	M	157	Firth of Lorn	**2021**	M	165	Firth of Lorn
2019	F	220	Firth of Lorn	**2021**	M	185	Firth of Lorn
2019	M	179	Firth of Lorn	**2021**	F	214	Sound of Jura
2019	F	152	Firth of Lorn	**2021**	M	173	Sound of Jura
2019	F	212	Firth of Lorn	**2021**	M	193	Sound of Jura
2019	M	185	Firth of Lorn				
2019	M	180	Firth of Lorn				
2019	F	217	Loch Aline				

Table 4: Receiver locations (decimal°) for the five-receiver array (left table) and the 10 receiver array (right table).

Station ID	Lat	Long
1	56.411	-5.627
2	56.034	-5.665
3	56.186	-5.815
4	56.313	-5.718
5	56.518	-5.776

Station ID	Lat	Long
1	56.518	-5.776
2	56.491	-5.655
3	56.411	-5.626
4	56.347	-5.683
5	56.315	-5.753
6	56.288	-5.697
7	56.279	-5.797
8	56.186	-5.816
9	56.075	-5.633
10	56.014	-5.712

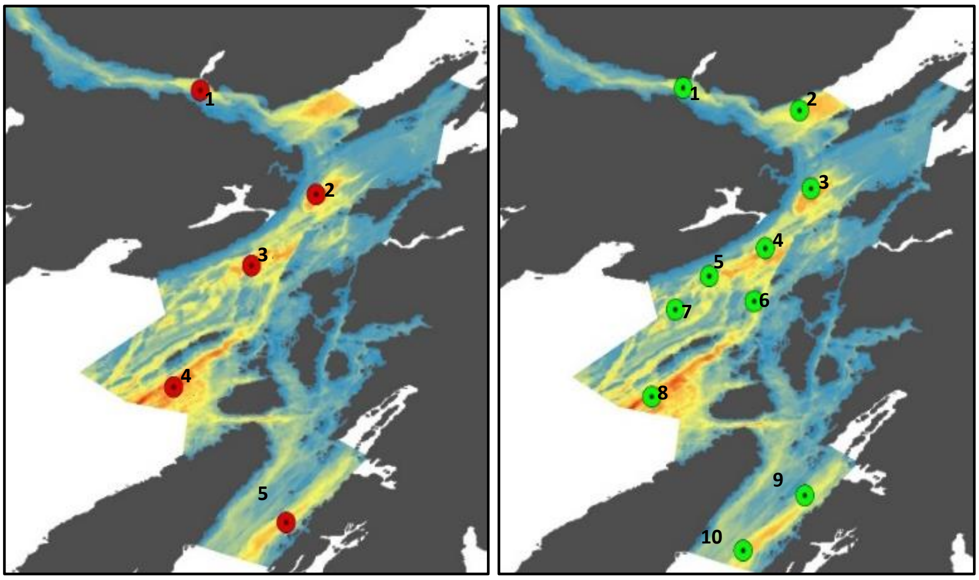

Figure 21: Location of the 10 and 5 receiver arrays in the Loch Sunart to the Sound of Jura MPA.

Detection data from all receivers were collected up until January 2021. Data collected during 2021 and 2022 will be published separately. Detection data shows all 41 skate tagged prior to 2021 were detected within the LSSoJ MPA at some point. The Detection Index (DI) was calculated for each skate, per month. This represents the proportion of days on which an individual was detected in each month. The DI ranges from 0.32–1.00. Females generally displayed regular usage of the area covered by the acoustic array. This was most noticeable in skate larger than 200 cm TL, but is also true of some of the smaller skate (e.g. 153 cm TL). The highest DI values were displayed by mature females (>200 cm TL) throughout 2020. Some females showed seasonal behaviour (e.g. 229, 159, 153 cm TL) and one female was only detected for one month following tagging (218 cm TL). Monthly DIs for males varied. Males that were present seasonally were mostly detected from August–February. There was evidence of high levels of site attachment in males with both mature and immature sizes displaying year-round detections.

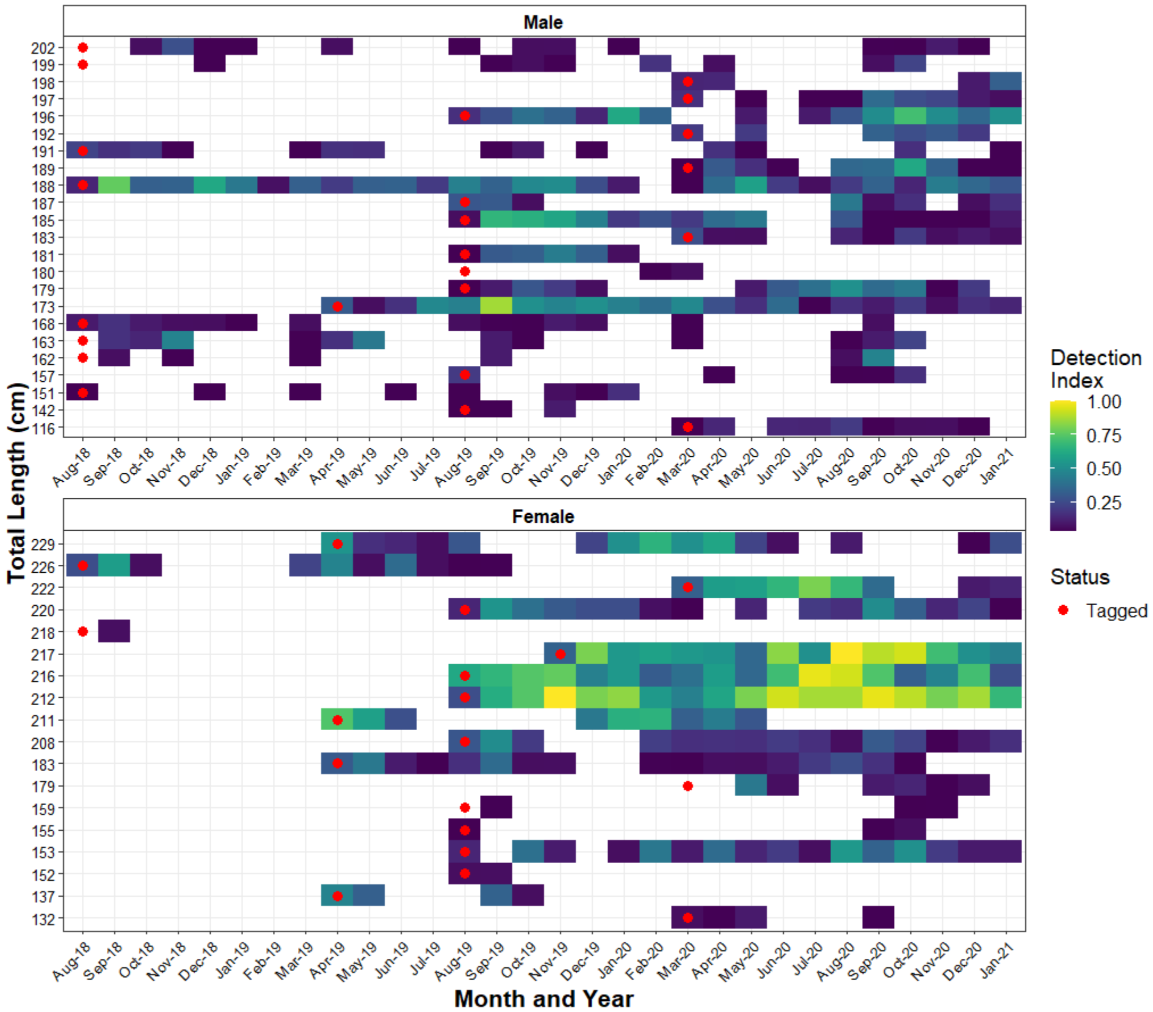

Figure 22: Monthly Detection index for male (top panel) and female (bottom panel) skate tagged prior to 2021 in the Loch Sunart to the Sound of Jura Marine Protected Area. Red marks show tagging month. Each row is an individual, and the row marker represents the total length of the skate in cm.

The data gathered since 2018 by the 10 receiver long term monitoring array which is more widely spread throughout the MPA further highlights the importance of the MPA to all age and sex classes. Data collected in 2021 and 2022 will be analysed as part of the SeaMonitor project (Garbett et al. 2021). Monthly DIs since 2018 are consistent with the level of residency around receivers inferred from previous work. However, the more recent data also illustrate residency behaviour in male skate. This may be due to the larger spatial coverage of receivers from 2018. This shows the importance of the whole area to flapper skate. This is especially true of mature female skate as shown by their higher DI values for female skate >200cm TL.

Initial findings into movements outside of the Loch Sunart to the Sound of Jura MPA

This work is subject to ongoing analysis and so the results presented here represent an initial summary that is subject to further development.

Key findings

- Mark-recapture/photo-ID data, movement models of archival data, and acoustic detections all show movements of skate between the LSSoJ MPA, South West Scotland, Northern Ireland and areas to the north of the MPA.
- The 2018 acoustic data and the 2016 archival datasets show a similar proportion of skate (80-90%) that show at least short term (>3 months) residency in the LSSoJ MPA.
- Mature individuals of both sex appear to be the most mobile. Of these mobile skate, most are of large females; this life-history category also displays high levels of residency in the LSSoJ MPA.
- Both Sound of Jura and Firth of Lorn contain skate that move beyond the boundaries of the MPA and were detected at other sites.
- Movements both in, and out, the LSSoJ MPA were documented.
- Circular movements originating in the LSSoJ MPA were documented. These show that movements away from the LSSoJ MPA vary in duration from a few weeks to 2 years.
- This helps place the LSSoJ MPA in the wider context of the skate's distribution, providing a 'spatial footprint' for the site, highlighting its potential to contribute to flapper skate management across a much wider are than just the west coast of Scotland.

Summary

Previous mark and recapture analysis suggests that 25% of skate in the MPA are transient (Neat et al., 2014). The 2016 acoustic data (Residency patterns section) show 39 % of skate displayed short-term residency (>three months) and 9% displayed long-term residency (>12 months) around receivers in the Firth of Lorn (Lavender et al., 2021b). Neither of these studies had detection data for skate outside the LSSoJ MPA, but they were suggested due to the maximum depths some skate appeared to have used being deeper than water depths found in the MPA. In order to address this, a tidal based geolocation model (Pinto et al., 2016) was used to model the movements of 25 skate tagged with archival tags in the LSSoJ MPA. Of these, one (4%) showed northward movement out of the LSSoJ MPA, being recaptured off Mallaig. Two (8%) displayed southward movement to Northern Ireland and Southwest Scotland before returning to the LSSoJ MPA. The remaining 22 (88%) showed highly localised movements in the LSSoJ MPA region over varying time scales from 3–772 days.

Evidence of movements between the LSSoJ MPA and out-lying regions from the mark-recapture and photo-ID data has been identified in one male (175 cm TL) and 11 females (155 – 213 cm TL) (Fig. 23) (Skatespotter data 2022).

Mark-recapture data

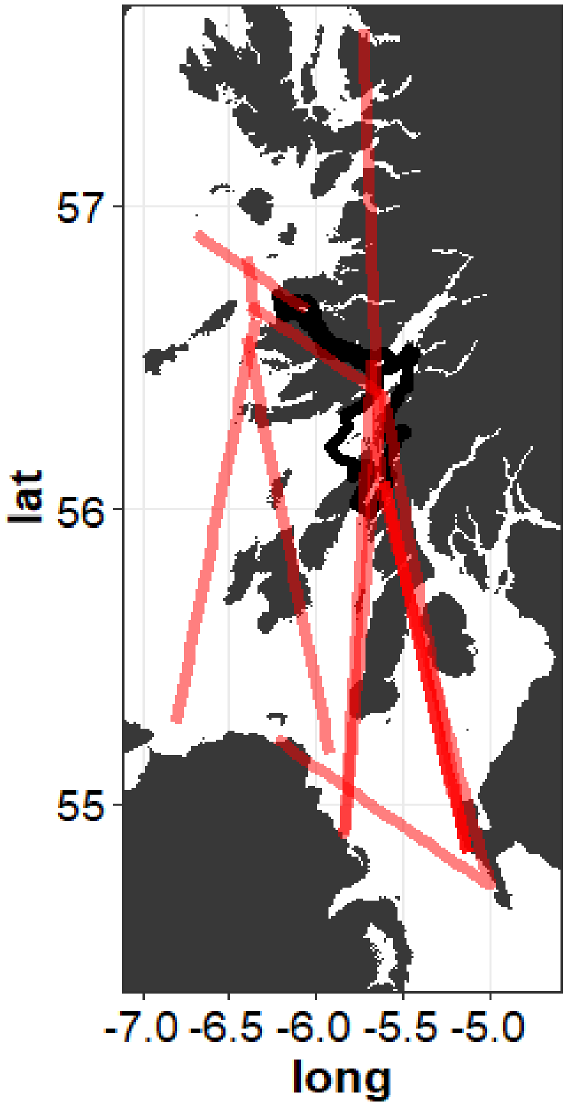

Figure 23: Mark-recapture and photo-ID data for skate that have been shown to move between the Loch Sunart to the Sound of Jura MPA and other areas. Captuer incidences of each indivudla connected by linear transects.

Archival geolocation model

Building on Pinto et al., (2016), archival data from 2011/2012 and 2016/2017 (Table 5) was analysed using a Hidden Markov geolocational model. This model searches for tidal patterns in the depth data and uses this to provide an estimate of location. These estimates are further refined using max depth data and a swim speed distance buffer, see (Pinto et al., 2016) for details.

Table 5: Skate (tagged 2017 or earlier) for which archival depth data were recovered and modelled using a Hidden Markov geolocation model (see Fig. 24).

ID	***TAG ID***	***SEX***	***TL (cm)***	***Deployed***	***Retrieved***	***Days deployed***	***TAG LAT***	***TAG LONG***	***RECAP LAT***	***RECAP LONG***
1	***7967***	M	110	19/10/2011	06/10/2012	353	56.09	-5.61	56.09	-5.6
2	***1509***	F	134.6	17/03/2016	20/04/2017	399	56.39	-5.62	56.39	-5.62
3	***1533***	F	154.9	14/03/2016	08/10/2016	208	56.39	-5.62	56.38	-5.62
4	***1538***	F	154.9	15/03/2016	19/07/2017	491	56.39	-5.62	57.01	-5.83
5	***1522***	F	160	16/03/2016	18/04/2017	398	56.39	-5.62	56.39	-5.62
6	***8828***	M	174	31/10/2012	19/11/2012	19	56.09	-5.61	56.09	-5.61
7	***1558***	F	174	13/03/2016	28/05/2016	76	56.32	-5.7	56.39	-5.62
8	***7972***	M	185	19/10/2011	13/04/2012	177	56.09	-5.62	56.09	-5.62
9	***1552***	F	185.4	13/03/2016	02/04/2016	20	56.32	-5.7	56.32	-5.7
10	***1536***	M	188	14/03/2016	23/10/2016	223	56.39	-5.62	56.36	-5.64
11	***1520***	M	190.5	16/03/2016	13/07/2016	119	56.39	-5.62	56.36	-5.64
12	***1523***	M	193	16/03/2016	26/05/2016	71	56.39	-5.62	56.36	-5.64
13	***1511***	M	195.6	17/03/2016	28/08/2016	164	56.39	-5.62	56.39	-5.62
14	***1548***	M	195.6	16/03/2016	21/04/2017	401	56.39	-5.62	56.39	-5.62
15	***1518***	M	198.1	16/03/2016	22/03/2017	371	56.39	-5.62	56.39	-5.62
16	***1525***	F	200.7	19/04/2017	03/05/2017	14	55.95	-5.78	55.95	-5.78
17	***1539***	F	200.7	15/03/2016	29/04/2016	45	56.38	-5.62	56.36	-5.64
18	***1574***	F	203.2	03/03/2016	09/06/2016	98	56.38	-5.62	56.36	-5.64
19	***1507***	F	205.7	17/03/2016	18/05/2016	62	56.39	-5.62	56.36	-5.64
20	***1526***	F	205.7	16/03/2016	19/03/2016	3	56.38	-5.62	56.39	-5.62
21	***1547***	F	208.3	15/03/2016	26/04/2018	772	56.38	-5.62	56.39	-5.62
22	***1512***	F	213.3	17/03/2016	13/07/2016	118	56.39	-5.62	56.39	-5.62
23	***1502***	F	215.9	19/04/2017	26/02/2019	678	56.07	-5.63	56.09	-5.61
24	***1519***	F	218.4	19/04/2017	31/03/2019	711	56.07	-5.63	56.07	-5.63
25	***7968***	F	221	07/11/2011	05/04/2012	150	56.01	-5.82	56.07	-5.63

The top ten most likely tracks were plotted to show reconstructed movements of the tagged skate. Most skate showed localised movements in the LSSoJ MPA or surrounding region. This included skate ID 14 (M) and 21 (F), over 401 and 772 days at liberty, respectively, as shown in Fig. 24.

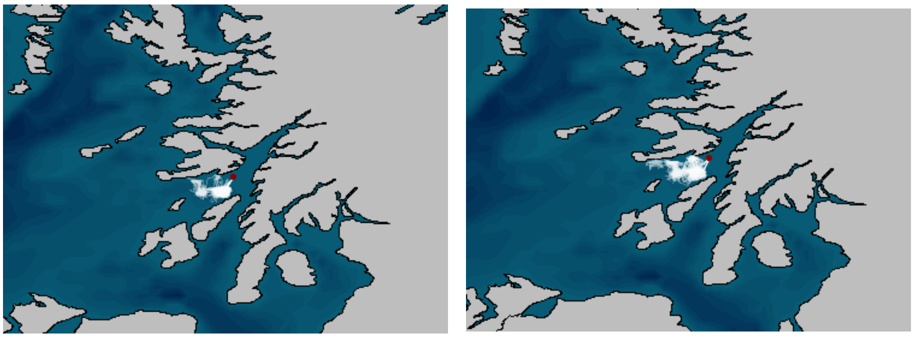

Figure 24: Top ten most likely tracks from skate ID 14 (M) and 21 (F) (401 and 772 days at liberty respectively) as examples of highly localised movements in the LSSoJ MPA or surrounding region. See Table 5 for details. Red point shows position of recapture. In cases where this is the same as the release position (green point), only the red dot will be seen.

Three skate were predicted at having made significant movements out of the MPA region (Fig. 25):

- No. 4. Immature female (154 cm TL) recaptured off Mallaig after 491 days (one-way movement)
- No. 23. Mature female (216 cm TL) 678 days (return movement)
- No. 24. Mature female (218 cm TL) 711 days (return movement)

The movements of No. 4, which was recaptured off Mallaig, show connectivity between the LSSoJ MPA and areas to the north. The movements of No. 23 and 24 show connectivity with the south-west of Scotland and Northern Ireland before returning to the LSSoJ MPA, after 678 and 711 days, respectively, where they were recaptured (Fig. 25).

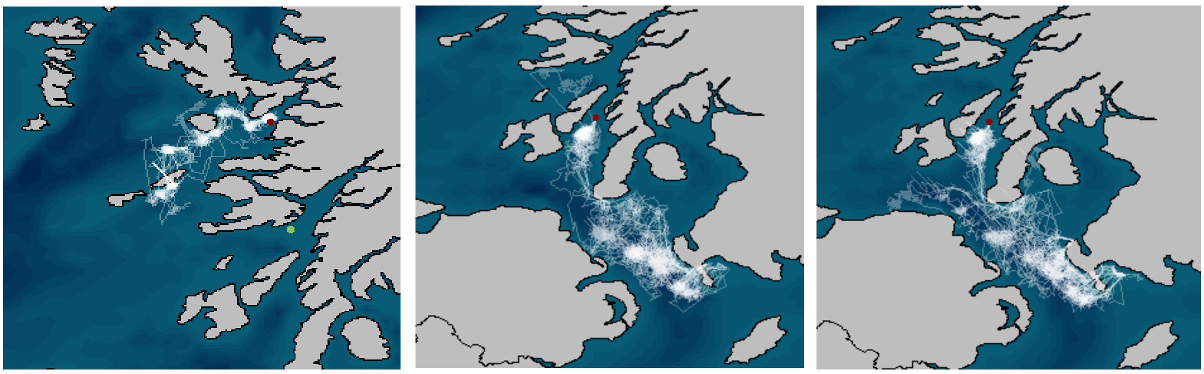

Figure 25: Modelled movements of female skate 4 (left), 23 (middle) and 24 (right) out of the LSSoJ MPA region. See Table 5 for details. Red point shows position of recapture. In cases where this is the same as the release position (green point), only the red dot will be seen.

2018 acoustics

The 2018 acoustic study in the LSSoJ MPA benefitted from other receivers deployed in Scottish, Northern Irish and Irish waters under the COMPASS, SeaMonitor and Atlantic Salmon Trust projects. The tags deployed in the LSSoJ MPA were compatible with all these receivers. This has so far resulted in the detection of 6 skate beyond the LSSoJ MPA boundaries (Fig. 26):

- 2 males 180, 198 cm TL
- 4 females 211**,** 229, 222, 226 cm TL

Of these, three have subsequently been detected back within the LSSoJ MPA, both males and a 229 cm TL female.

The results from all three methods (mark-recapture, archival geolocation modelling and passive acoustic telemetry) show similar movements, with movements between the LSSoJ MPA being repeatedly connected to the, the South West of Scotland and Northern Ireland. The geolocation models and mark-recapture data also show movements between the LSSoJ MPA and Loch Torridon to the north of the LSSoJ MPA. These movements suggest that the egg nursery at the Red Rocks and Longay proposed MPA (Marine Scotland) is within the range of skate that use the LSSoJ MPA, but there is no data to suggest the scale of any connectivitiy between the sites.

The different data sources, along with the data in the "Set up long term monitoring array" section, all suggest that skate in the LSSoJ MPA exhibit both short-range movements (i.e., periods of residency and site attachment) as well as longer range movements beyond the LSSoJ MPA, resulting in site fidelity and transiency. These movements occur in all life-history categories studied. For example, mature females display both site affinity and transiency. This suggests that the skate population undertake a partial migration strategy, with some skate displaying high levels of residency in the site, while others of a simialr life history class, make wider movements beyond the MPA. Some skate that display wide raning movements beyond the MPA do return, benefitting from the management measures repeatably over their lives. There is not a strong seasonal trend in movements beyond the LSSoJ MPA, with some skate moving out of the LSSoJ MPA, travelling significant distances (>150km), and returning to the LSSoJ MPA in relatively short time periods (6 days), while others move out of the LSSoJ MPA for long periods of time. More data is being collected on the wider movement of skate between the LSSoJ MPA and will be analysed through the SeaMonitor project.

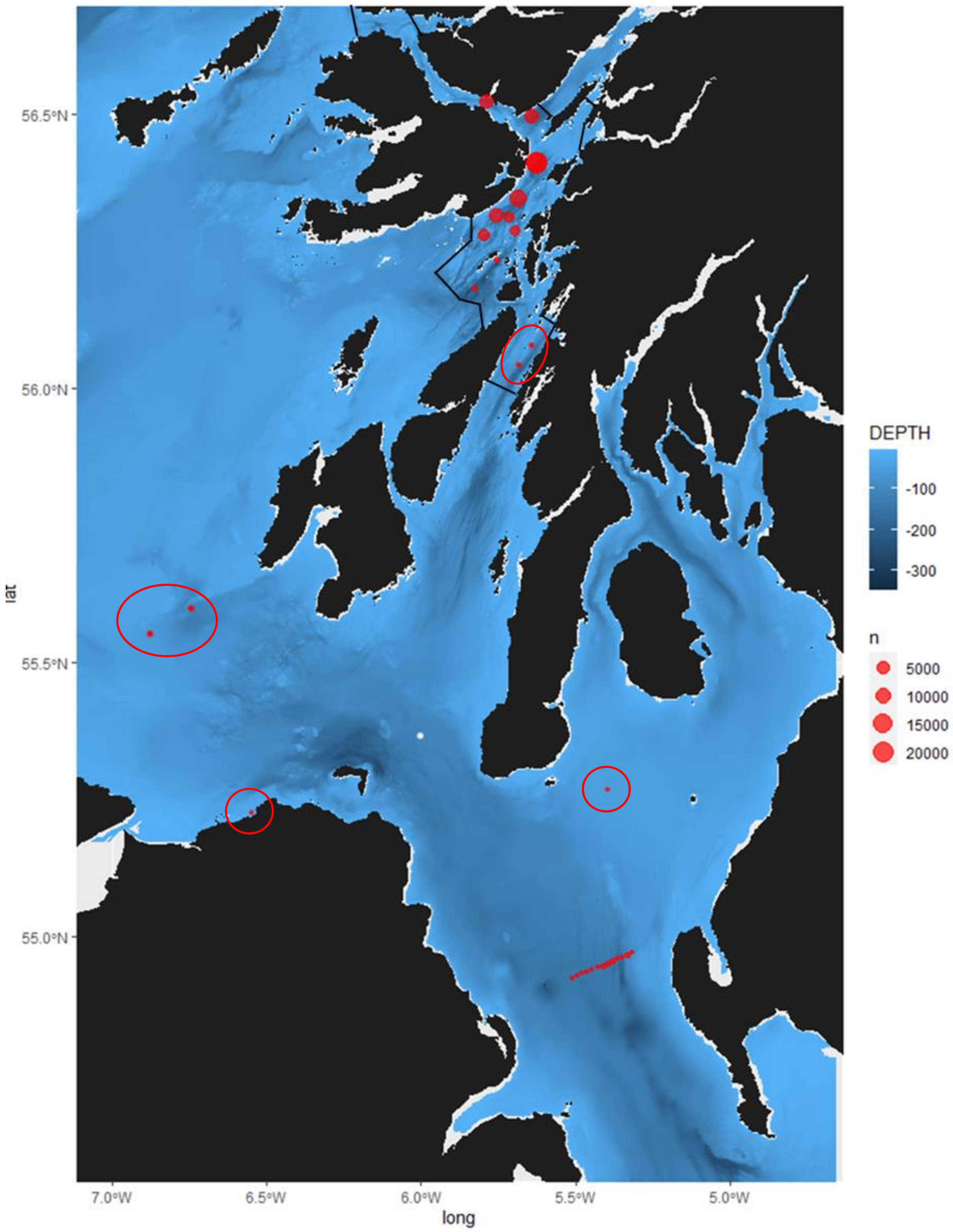

Figure 26: Detections of skate tagged in the Loch Sunart to the Sound of Jura Marine Protected Area by receivers both within and beyond the management boundary (shown by the black boundary).

Behavioural responses of skate to catch-and-release angling

This section summarises (Lavender et al., Accepted). All figures are adapted from this paper.

Key findings

- During catch-and-release angling from charter vessels, the changes in depth and temperature experienced by captured skate typically exceed natural variability.
- Immediately following release, individuals typically move into deeper water and exhibit short periods (usually 1–2 hours in duration) of low vertical activity. However, overall, in the 12 hours following release, vertical activity is typically around 38 % higher than in comparable undisturbed periods.
- Three individuals (14 %) exhibited irregular post-release behaviour in the form of rapid, transient re-ascents towards the surface following release.

Summary

The behavioural responses of flapper skate to catch-and-release angling were described using the 2016/17 archival (depth and temperature) data. Data analysed included observations for 21 tag deployment/retrieval events (Fig. 26) and five recreational angling events (Fig. 27) conducted from charter vessels in the LSSoJ MPA. During catch-and-release angling from charter vessels, the changes in depth and temperature experienced by captured skate typically exceed natural variability. The skate are also subject to temperatures beyond their normal experience while out of the water. After rod and line capture, post-release, behavioural change was apparent from visual inspection, regression and functional data analysis of the time series. Immediately following release, movements into deeper water and short periods of low vertical activity (typically 1–2 hours in duration) were common (Fig. 4). However, overall, average vertical activity was typically around 38 % higher in the 12-hours following release than in undisturbed activity. A small number of individuals (n = 3, 14 %) exhibited irregular post-release behaviour in the form of rapid, transient re-ascents towards the surface following release (Figs. 26 & 27). However, the cause of this behaviour is unclear.

Collectively, these results indicate that flapper skate behaviour is relatively resilient to catch-and-release angling from charter vessels, but post-release behavioural changes, especially irregular post-release behaviour, are sufficiently notable to indicate that further research is required on the impacts of this practice.

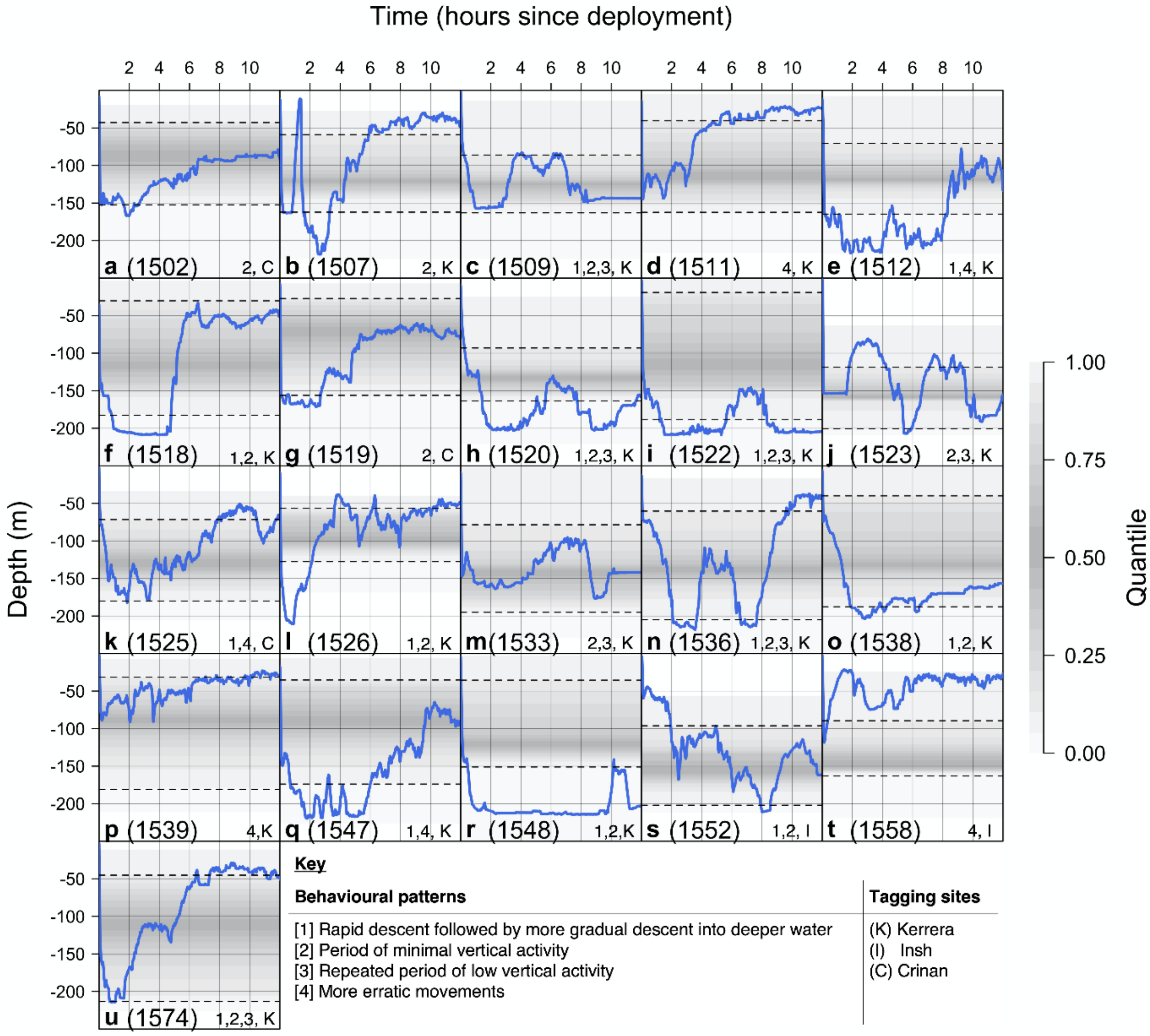

Figure 27: Depth time series following tag deployment. Each plot (a–u) shows the observed time series (in blue) for a specific individual. The background shading marks the quantiles of observed variation in depth based on the rest of each individual's time series, with quantiles near the middle of the distribution shaded more darkly than quantiles towards the edge of the distribution. The dashed lines mark the 25th and 75th quantiles respectively. Depth observations beyond these lines are considerably shallower or deeper than average, while depth observations beyond the shading are more extreme than observed outside of capture event(s). Numbers and letters mark distinct patterns and tagging locations, respectively.

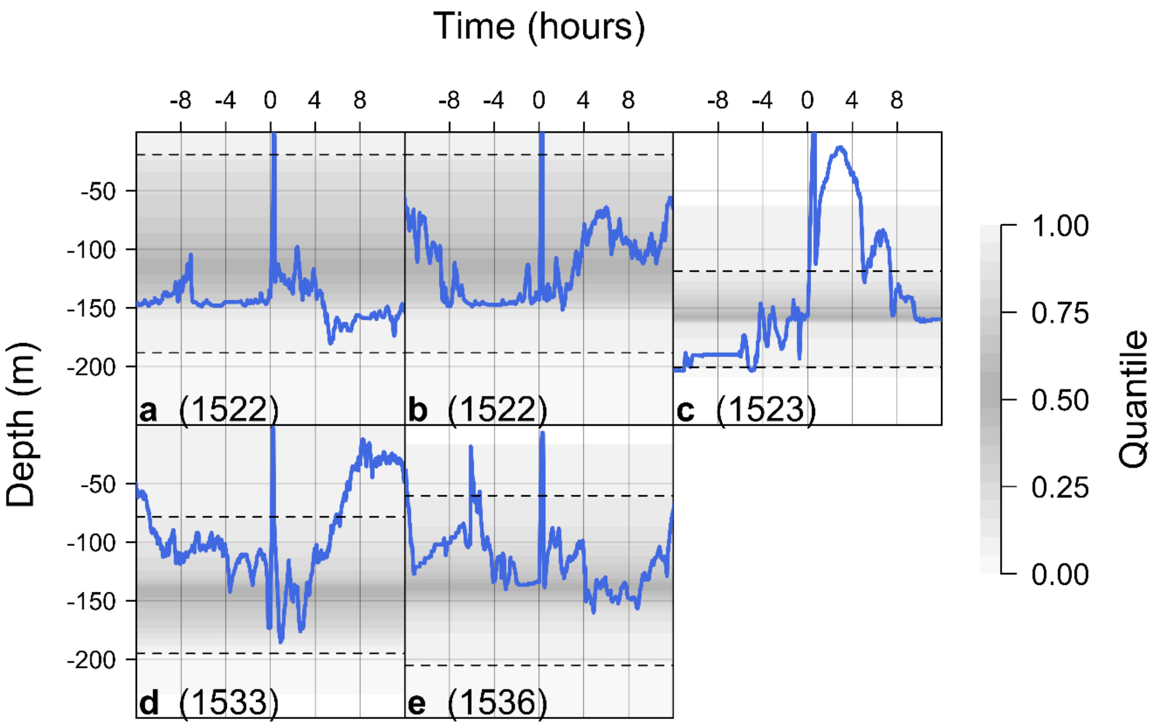

Figure 28: Depth time series around recreational catch-and-release angling events during individuals' time at liberty. Each plot (a–e) shows the observed time series (in blue) around a capture event for a specific individual. The background shading marks the quantiles of observed variation in depth based on the rest of each individual's time series, with quantiles near the middle of the distribution shaded more darkly than quantiles towards the edge of the distribution. The dashed lines mark the 25th and 75th quantiles respectively. Depth observations beyond these lines are considerably shallower or deeper than average, while depth observations beyond the shading are more extreme than observed outside of capture event(s).

Initial findings into capture stress

This work is subject to ongoing analysis and so the work presented here represents an initial summary that is subject to further development.

Summary

The blood samples taken from tagged skate (BS1 at the time of boarding and BS2 at the time of release) were analysed for the following parameters: Blood pH, partial pressure of carbon dioxide, partial pressure of oxygen, base excess, bicarbonate and lactate using a CG4+ cartridge and iStat hand-held analyser (i-STAT, Abaxis Veterinary Diagnostics, Union City, California 94587,USA). Blood glucose was also measured using an Accu-Check® mobile glucometer (Roche Diagnostics, Risch-Rotkreuz, Switzerland). Plasma was stored frozen and analysed at a later date to obtain values for potassium, total calcium, and magnesium. The relationship between these blood parameters and fight time, wait time (time between landing and BS1 or BS2), total handling time (defined as fight time plus wait time), skate weight (estimated from total length and disc width), and bottom temperature were explored.

Initial results suggest longer fight or total handling times result in a greater degree of acidosis, with the degree of acidosis worsening between BS1 and BS2. Skate overall appeared to exhibit a relatively mild metabolic acidosis when compared to other elasmobranchs caught by rod and reel (Hoffmayer et al., 2012; 2015; Mohan et al., 2020; Whitney et al., 2017), despite relatively long fight times. Due to temperature-induced alterations in pH and blood gasses and lack of baseline values, meaningful comparisons with other studies can be challenging. However, compared to baseline blood values determined in similar species, flapper skate in this study had lower pH and higher lactate (Cicia et al., 2012), suggesting a degree of metabolic disturbance (acidosis) was induced by angling. Peak values of circulating lactate have been shown to slowly develop in some elasmobranch species, sometimes greater than 1 hour after a stressful event. (Richards et al., 3003; Cliff & Thurman 1984). The maximal point of metabolic disturbance was not determined for skate in this study, and it is likely that blood acid base alterations may take some time to normalise post-capture. There was a greater degree of acidosis with warmer temperatures at depth. This finding suggests that flapper skate may be at greater risk of complications due to capture and handling in the summer months. Increased temperatures have been linked to increased secondary stress response and acidosis (Hoffmayer et al., 2012; Hyatt et al., 2018) and increased mortality in elasmobranchs (Cicia et al., 2012).

The study's preliminary results suggest that flapper skate experience increased stress with longer fight or total handling times and when caught in warmer waters. This has implications for angling where recommendations could be made to use suitable techniques that will keep fight and handling times as short as possible, especially in months of the year when water temperatures are highest.

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