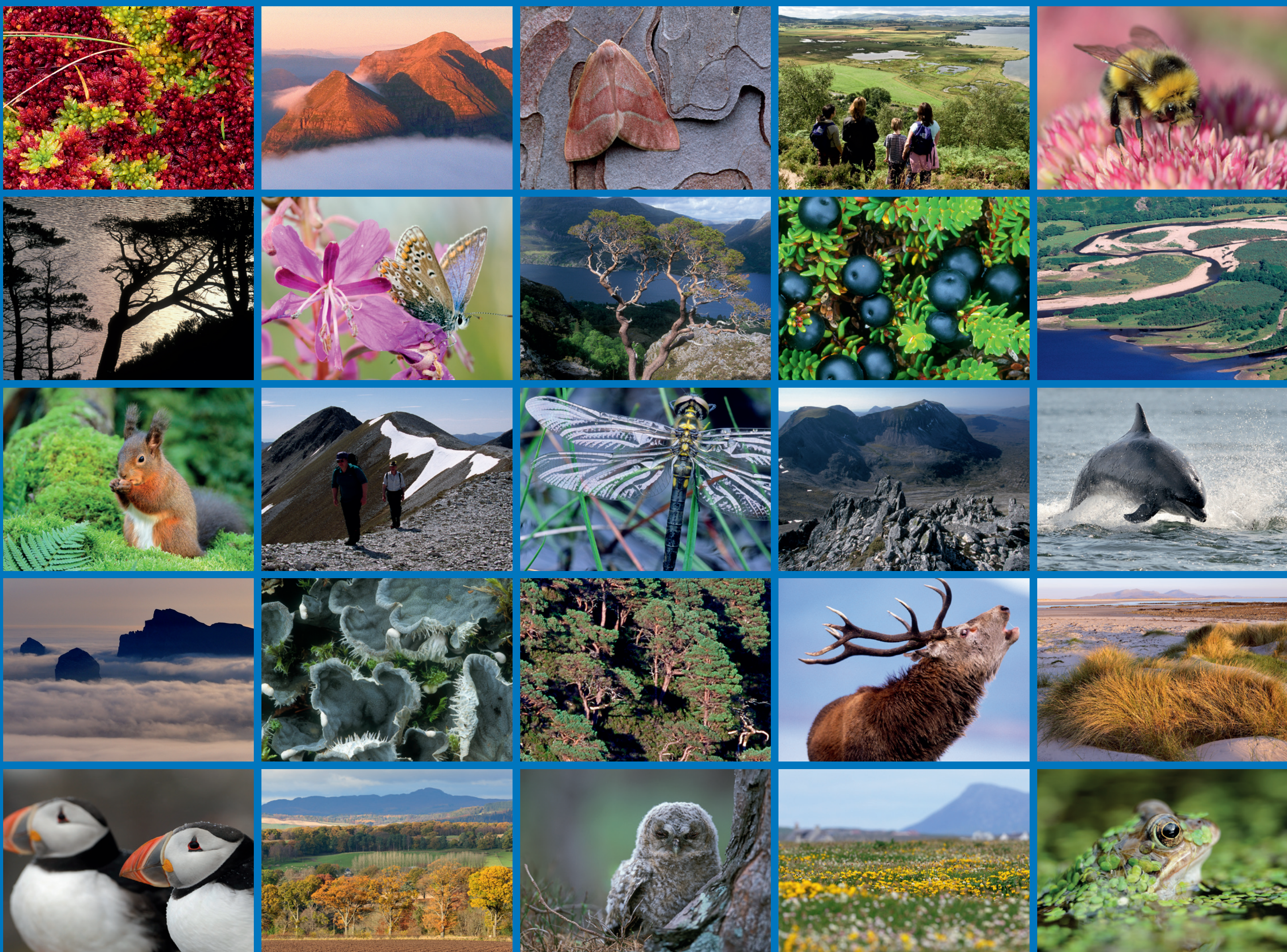
Scottish Natural Heritage
Research Report No. 1011

Spatial ecology of flapper skate (*Dipturus intermedius – Dipturus batis complex*) and spurdog (*Squalus acanthias*) in relation to the Loch Sunart to the Sound of Jura Marine Protected Area and Loch Etive



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RESEARCH REPORT

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RESEARCH REPORT

Summary

Spatial ecology of flapper skate (*Dipturus intermedius – Dipturus batis complex*) and spurdog (*Squalus acanthias*) in relation to the Loch Sunart to the Sound of Jura Marine Protected Area and Loch Etive

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Keywords

Acoustic; tagging; Data Storage Tags; movement; habitat use; management; elasmobranch; Marine Protected Areas

Background

Elasmobranchs (sharks, skates and rays) have the potential for high mobility. However, where they show certain types of behaviour such as residency or site fidelity, Marine Protected Areas (MPAs) can be a valid option for their conservation. Such behaviour has been identified in the flapper skate (*Dipturus intermedius*), resulting in the Loch Sunart to the Sound of Jura MPA being established for this species. One aim of this project was to better understand how the skate use the MPA using an array of acoustic sensors in the Firth of Lorn and Sound of Mull (the Firth of Lorn acoustic array). The project also set out to explore the spatial behaviour of spurdog (*Squalus acanthias*) in Loch Etive, a sea loch that is connected to and lies adjacent to the MPA. In both cases, tagging technologies including acoustic and archival tags were used.

Main findings

Flapper skate (*Dipturus intermedius*)

- Tagged females displayed higher occupancy in the Firth of Lorn than males. The average number of days females remained in the Firth of Lorn over the course of the project (13 months) was 85, whereas for males it was 31. Four female skate were detected for over 200 days each. Only two males were detected for longer than 50 days.
- Skate mostly remain in water depths between 100 – 150 m over summer months (March – August) with some individuals having a larger depth range over winter months (September – February).

Spurdog (*Squalus acanthias*)

- Both sexes have high residency in Loch Etive. 95% of tagged spurdog were detected in the loch for more than 250 days.
- Only male spurdog were tagged in the Firth of Lorn. They moved away between August and November, returning in November and remaining in the Firth of Lorn over winter. None of these were detected in Loch Etive.

- There was very limited evidence of females from the loch moving into the Firth of Lorn with 2 spurdog being detected in the Firth of Lorn.
- Where the movements of male and female spurdog could be compared, there were no discernible differences between the sexes.

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1. PROJECT BACKGROUND

1.1 The Loch Sunart to the Sound of Jura Marine Protected Area

The Loch Sunart to the Sound of Jura Marine Protected Area (MPA) covers a large area of 720 km^2 (Fig 1.). It is comprised of bedrock-dominated seabed, divided into narrow, stratigraphically constrained and glacially-over-deepened basins more than 200 m deep, and a vertical cliff up to 150 m high in the central Firth of Lorn (Howe *et al.* 2015).

The flapper skate is an attractive species to sea anglers who travel from all over the world to tick the species off their "bucket list". All angling for the species in Scotland is catch and release and the data provided by anglers through tagging projects dating back more than 30 years has proved invaluable in developing a protection strategy for the species. Across the MPA many individuals have been recaptured multiple times over many years, providing strong evidence for limited home ranges and site fidelity in some mature individuals (Neat *et al.* 2014). These data led to the proposal of the Loch Sunart to the Sound of Jura MPA by the Scottish Sea Angling Conservation Network (SSACN). A subsequent acoustic tag and Data Storage Tagging (DST) research project in the area was completed in 2012 (Neat *et al.* 2014) and provided additional data supporting the site as an MPA for common skate. The site was designated a Nature Conservation MPA by the Scottish Government in 2014 (Loch Sunart to the Sound of Jura Nature Conservation Marine Protected Area Order, 2014). Current management is a combination of closed areas where no mobile gear is allowed, with the remaining area of the MPA being subject to a seasonal mobile fishery that prohibits the use of tickler chains, as this has been shown to reduce the bycatch of skate (Kynoch *et al.* 2015). Set nets and long lines are prohibited from the entire protected area. Loch Sunart is completely closed to demersal mobile gears, set nets and long lines.

1.2 Loch Etive

Loch Etive is situated on the Scottish west coast (Fig. 1). This sea loch is approximately 30 km long and has a mean width of 2 km. It is separated into two basins, an upper (inland) basin with a maximum depth of 145 m, and a lower (seaward) basin with a maximum depth of 70 m.

These basins are separated by a shallow sill 13 m deep. A second shallow sill, approximately 5 m deep, separates the lower basin from the ocean causing a tidal water fall (the Falls of Lora) at the mouth of Loch Etive (Hsieh *et al.* 2013).

Recreational angling for spurdog in the loch is a popular activity throughout the year and anglers have contributed to a mark and recapture programme in the loch, the Scottish Shark Tagging Programme (SSTP). This in combination with a pilot archival and acoustic tagging project (Thorburn *et al.* 2015) show that some spurdog make repeated use of the loch over the course of a year, even residing in the upper basin over winter, however the full extent of this behaviour is unknown.

1.3 Elasmobranch populations

Elasmobranchs (sharks, skates and rays) have a cartilaginous skeleton and are strong 'K' strategists, being slow growing, late to mature, having low fecundity and producing large, well-developed offspring. Large offspring are vulnerable to accidental capture in towed gear immediately after hatching. These life history characteristics often result in slow population recoveries.

Population segregation based on age or sex is a common feature of many elasmobranch species (Hurst *et al.* 1999; Alonso *et al.* 2002), resulting in different age and sex classes displaying different movement behaviour (Pardini *et al.* 2001; Portnoy *et al.* 2010; Daly-Engel *et al.* 2012).

Despite the wide-ranging behaviour of some elasmobranchs, it has been shown that many species make use of the same areas repeatedly (Speed *et al.* 2010). This recurrent use of an area is often broadly termed 'site fidelity'. Site fidelity varies considerably between species and habitats but can range from daily fidelity (e.g. Goldman & Anderson 1999) to seasonal fidelity (e.g. Thorburn *et al.* 2015). Some species appear to display residency (Papastamatiou *et al.* 2009, Andrews *et al.* 2009).

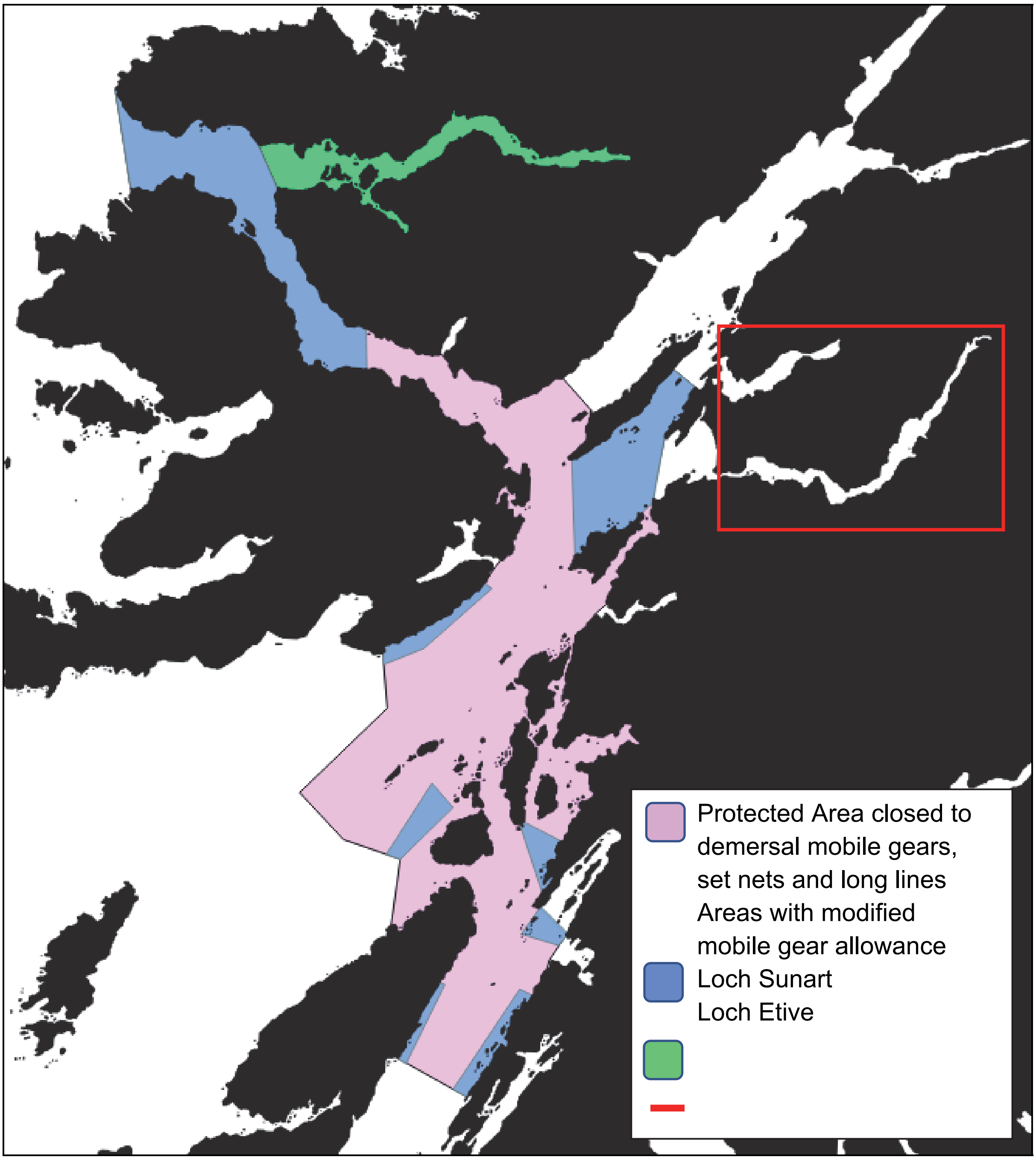

Figure 1. The Loch Sunart to the Sound of Jura MPA and Loch Sunart. Colours highlight the different management options in the Protected Area. Loch Sunart is completely closed to demersal mobile gears, set nets and long lines. Red box shows Loch Etive.

1.4 Flapper skate (*Dipturus intermedius*)

In 2009 it was discovered that what was previously (and still is in some policy measures) referred to as the common skate is actually two clearly distinct species - the flapper skate (*Dipturus intermedius*) and the blue skate (*Dipturus flossada*) (Iglesias *et al.* 2009). The larger flapper skate occurs in the northern North Sea and off the northwest coast of Scotland, and the blue skate is the predominant species in the Celtic Sea and around Rockall (Griffiths *et al.* 2010). The two species' ranges overlap in the Celtic Sea and the offshore area to the west coast of Scotland. Having been declared locally extinct in several areas around the UK (Brander 1981; Rogers and Ellis 2000), concern about the conservation of the species has been reflected in national policy and legislation in the context of both fisheries and biodiversity. For example, the landing of the common skate (both species) is prohibited in Scotland (SSI 2012 no. 63 - The Sharks, Skates and Rays (Prohibition of Fishing, Transhipment and Landing) Order 2012). Common skate is listed as a key UK Biodiversity Action Plan priority marine species, and in Scotland is part of the Priority Marine Features list. In addition, common skate is a search feature for the identification and selection of marine protected areas in Scotland, which lead to the designation of the Loch Sunart to the Sound of Jura MPA (see section 1.1).

The flapper skate is one of the largest fish in Scottish waters reaching over 2 m in length and over 100 kg in weight. Research on the flapper skate population within the MPA has shown the species to display high levels of residency (Neat *et al.* 2014), with individuals remaining in a relatively small spatial area for many weeks and months, up to a full year (Neat *et al.* 2014), and transient individuals that move out of the area and do not return (Neat *et al.* 2014).

1.5 Spurdog (*Squalus acanthias*)

Spurdog (*Squalus acanthias*) are distributed worldwide throughout temperate continental shelf seas. This species has low fecundity and a gestation period of up to 24 months. Due to historical exploitation of spurdog, the North East Atlantic biomass in 2010 was estimated to be about 23% compared to 1955 numbers and 19% compared to 1905 (Oliveira *et al.* 2013), but numbers appear to have stabilised over the last decade (ICES, 2016).

Spurdog in the NE Atlantic are currently viewed as a single stock (Vince, 1991), a designation based on mark and recapture tagging data demonstrating wide ranging movements throughout this region (Templeman 1976, 1984; Gauld and Macdonald 1982; Vince 1991). There is evidence suggesting more limited regional movements in some coastal areas (Campana *et al.* 2009; Carlson *et al.* 2014; Thorburn *et al.* 2015). In contrast, offshore units appear highly migratory (McFarlane and King, 2003; Campana *et al.* 2009). Spurdog are a Priority Marine Feature, though not included on the MPA search feature list.

2. OBJECTIVES

There were two main objectives of this project:

1) Assess the residency and fine-scale movements of flapper skate within the Loch Sunart to the Sound of Jura Marine Protected Area.
2) Assess the residency and fine-scale movements of spurdog within Loch Etive. Opportunistic tagging in the Firth of Lorn was also undertaken to give insight into how spurdog use the MPA.

3. METHODS

3.1 Acoustic array

3.1.1 Loch Sunart to the Sound of Jura MPA

Acoustic receivers (VEMCO VR2s and VR2 acoustic release) were moored at 39 sites throughout the Firth of Lorn and Sound of Mull (Fig. 2. & Table 1). This is henceforth referred to as the Firth of Lorn array. No receivers were placed in the southern part of the MPA in the Sound of Jura. Surface moorings consisted of 75-100 kg of ballast with a 18 mm line to a surface marker. In areas of exceptionally high tidal flow, an additional anchor was attached to the ballast. Acoustic units were attached to a main line, 25 – 50 m below the surface depending on the depth of water they were moored in.

Acoustic release (AR) units were attached to 50 kg of ballast and a 5 – 10 m rising length of 18 mm sea steel. The AR units were placed in specially designed release cans with 2 x 13 inch floats and up to 160 m of 7 mm Dyneema for ballast retrieval upon release. Moorings were installed between 7th and 9th March 2016 and all units (including ballast) were removed by 27th June 2017.

3.1.2 Loch Etive

In Loch Etive 10 receiver units were used. Nine within the Loch upstream of the Falls of Lora and one downstream of the Falls (Fig. 2). A similar mooring system was used with 35 kg of ballast attached to a 5 m length of 12 mm chain and a 20 kg Bruce anchor. A 12 mm line was attached to a marker buoy at the surface. Acoustic units were attached to the main line midway between the surface and the sea floor. Receiver units were moored on 14th and 15th June 2016 and removed on 20th and 21st July 2017.

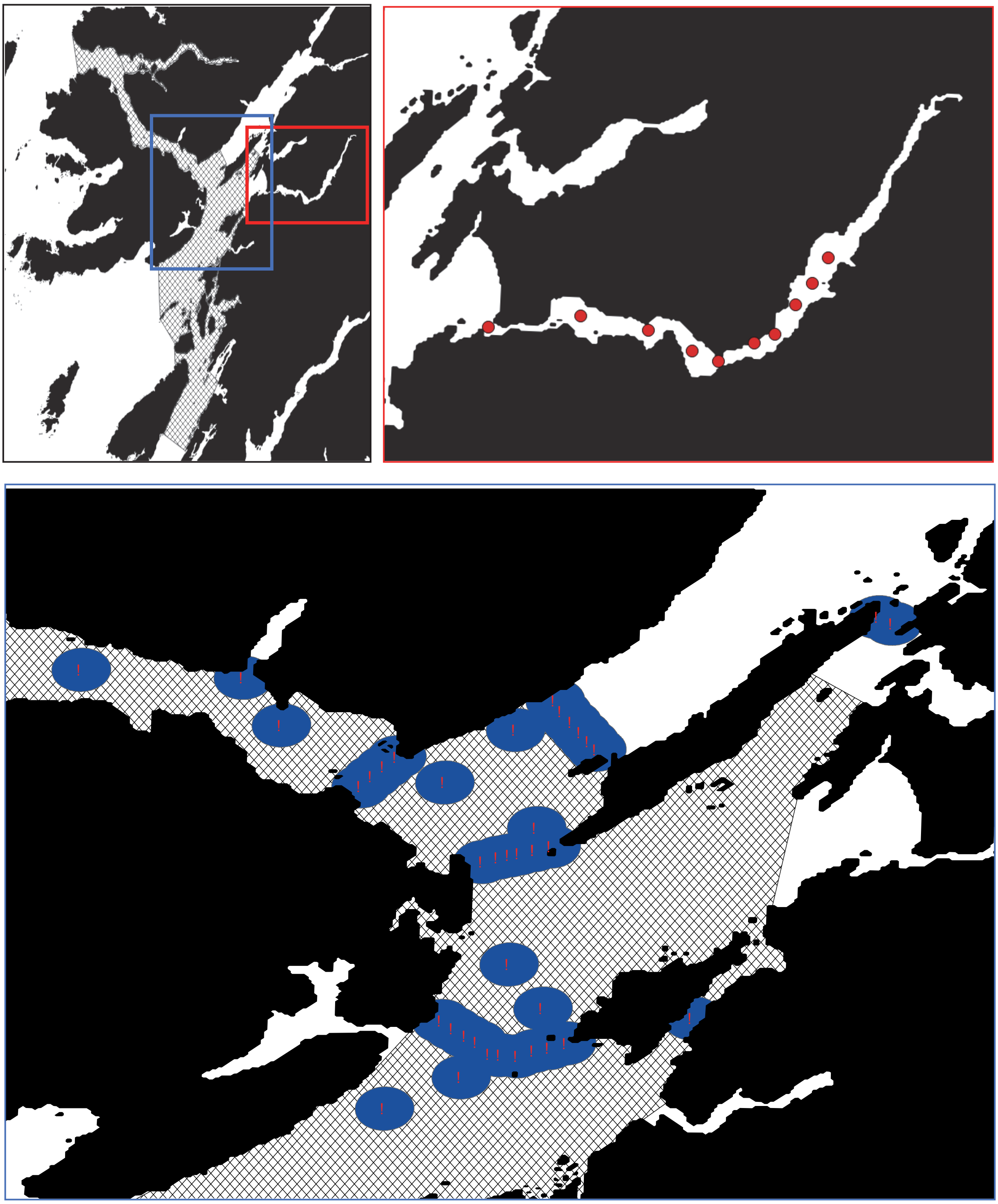

Figure 2. The location of acoustic receivers (red dots) within the Loch Sunart to the Sound of Jura Marine Protected Area (blue rectangle) – referred to as the Firth of Lorn array, and Loch Etive (red rectangle). Cross hatched region shows the area of the MPA protection, covering all management measures. The areas in blue on the bottom panel show the approximate detection range (1km) for the array.

3.2 Skate tagging

Tagging occurred at two main tagging sites; the Firth of Lorn and the Sound of Jura (Fig. 3). Skate were caught using individual lines with barbless hooks. Once caught, skate were brought to the surface and landed on to the deck of the boat. The skate were measured; total length (snout tip to tail tip) and disc width (wing tip to wing tip), both over the dorsal side of the body. A small fin clip was then taken from the trailing wing edge for genetic analysis. Data Storage Tags (DSTs) and acoustic tags were then fitted. Once tags were fitted, skate were returned to the water as quickly as possible either through a gate in the rear of the boat or via a lifting sling over the side.

Figure 3. Tagging locations (blue polygon) in the Loch Sunart to the Sound of Jura MPA. Spurdog tagged in the Firth of Lorn were tagged in the upper polygon.

3.2.1 Data storage tags

A combination of tags; Star Oddi milli-TD and Centre for Environment Fisheries and Aquaculture Science (CEFAS) G5 or G6as were used in this study. Pre-started tags were fitted externally, anchored through the leading edge of the wing on the left-hand side of the body. Two stainless steel pins were used to attach the tag to the dorsal side of the wing, through the cartilage and secured on the ventral side. Tags were secured in a specially made plastic housing which was placed on a silicon pad to provide protection to the skin. This method permits easy removal while ensuring long term attachment. Each tag was marked with a specific ID number and set to record depth and temperature every two minutes. All skate were released at their capture site within the Firth of Lorn or Sound of Jura. Tags were marked with contact details and notice of a £50 (Star Oddi) or £25 (CEFAS) reward for their return.

3.2.2 Acoustic tags

A combination of Thelma Biotel MP–13 and Vemco V13 tags were used, all operating on 69 KHZ. Acoustic tags were attached in a similar fashion to the DSTs. A single stainless-steel pin was used to anchor the tag on to the leading edge of the right wing. Tags were held in place with a Petersen disc either side of the wing and a silicon pad was placed under the disc on the dorsal surface to provide some protection from potential tag movement.

Figure 4. Tagging location on flapper skate. With the black acoustic tag (lower panel left) on the right wing and the white Data Storage Tag (lower panel right) on the left wing.

3.3 Spurdog tagging

In all cases, spurdog were caught using individual hook and line methods with barbless hooks. Landed spurdog were placed in an anaesthetising tank dosed with MS-222 anaesthetic (1 g in 10 L). Once anaesthetised, the spurdog were placed with their ventral surface exposed in a grooved work bench. Total length (snout to tail tip) and girth (around body posteriorly to pectoral fins and anteriorly to the dorsal fin) were measured. A small fin clip was then taken from the trailing edge of the dorsal fin for genetic analysis.

Figure 5. The position of tagging locations (blue areas) in Loch Etive and the Falls of Lora (A).

3.3.1 Data storage tags

Spurdog were only tagged with data storage tags (as well as acoustic tags) in the Firth of Lorn (Fig. 3). Pre-started Star Oddi milli-TD tags were fitted externally, anchored through the base of the dorsal fin using two stainless steel pins permitting easy removal (Fig. 5). As with skate, each tag was marked with a specific ID number and set to record depth and temperature every two minutes; tags were marked with contact details and notice of a £50 reward for return.

3.3.2 Acoustic tags

Acoustic tags were internally inserted into the peritoneal cavity. A small slit, approximately 1 cm long, was made along the ventral surface in the abdominal wall approximately halfway between the pectoral and anal fins. A pre-started acoustic transmitter tag was inserted through the opening which was then closed with monofilament suture through the muscle and skin layer. A combination of Thelma Biotel LP-7.3, LP-9, MP-13 and VEMCO V13s were used.

Once tagged, the spurdog were placed in a recovery tank of clean seawater until they started moving. They were then placed over the side of the vessel and held head into the current to force ventilate until they could swim. All spurdog were released at their capture point.

Figure 6. An anaesthetised spurdog with a Data Storage Tag fitted to the dorsal fin.

All tagging procedures on skate and spurdog were authorised by the United Kingdom Home Office.

3.4 Data

Depth data from double tagged (acoustic and DST) skate where DSTs were returned was filtered alongside the acoustic data. If a fish had been detected within a 24-hour period (as defined by day of the month), then the skate was deemed to have been present in the MPA for that 24-hour period. The DST depth data was extracted for any 24-hour period when the skate were detected to provide information on how skate use depth habitat within the MPA.

4. RESULTS

4.1 Flapper skate

A total of 63 skate were tagged with DSTs, 18 in the Sound of Jura between 13th - 14th March 2016 and 18th - 19th April 2017, and 45 in the Firth of Lorn between 13th - 17th March 2016. Of these, 41 were also fitted with acoustic tags: 4 in the Sound of Jura and 36 in the Firth of Lorn (Fig. 3). One tag, ID 11, fell off immediately when returning the skate to the water due to snagging on the edge of the boat. See Tables 1 and 2 for details of skate tagged.

Table 1. Details of skate tagged in the Sound of Jura (SOJ). Skate ID = number assigned to enable cross-referencing with other figures and images in this document. If the ID number is in red and bold, the Data Storage Tag was returned for this skate. TL = Total Length in cm, DW = Disc Width from wing tip to wing tip across the dorsal surface. 'DST' indicates if a Data Storage Tag was fitted. 'Acoustic' indicates if an acoustic tag was fitted, if the Y is coloured red, then this tag was detected by the Firth of Lorn array.

Date	Skate Id	Tl (Cm)	Dw (Cm)	Sex	Dst	Acoustic	Tagging Location	Days Detected
13/04/2016	**41**	213	160	F	Y		SOJ	
13/04/2016	42	211	163	F	Y		SOJ	
13/04/2016	43	211	165	F	Y		SOJ	
13/04/2016	**44**	208	157	F	Y		SOJ	
14/04/2016	45	213	163	F	Y	Y	SOJ	
14/04/2016	**46**	211	160	F	Y	Y	SOJ	
14/04/2016	47	203	160	F	Y	Y	SOJ	3
14/04/2016	48	198	152	F	Y	Y	SOJ	
14/04/2016	**49**	208	163	F	Y		SOJ	
14/04/2016	50	211	165	F	Y		SOJ	
14/04/2016	51	221	168	F	Y		SOJ	
18/04/2017	**57**	201	122	M	Y		SOJ	
18/04/2017	58	210	163	F	Y		SOJ	
19/04/2017	**59**	201	163	F	Y		SOJ	
19/04/2017	60	216	165	F	Y		SOJ	
19/04/2017	61	193	159	F	Y		SOJ	
19/04/2017	62	218	170	F	Y		SOJ	
19/04/2017	63	191	145	M	Y		SOJ	

Table 2. Details of skate tagged in the Firth of Lorn (FOL). Skate ID = number assigned to enable cross-referencing with other figures and images in this document. If the ID number is in bold and red, the Data Storage Tag was returned for this skate. TL = Total Length in cm, DW = Disc Width from wing tip to wing tip across the dorsal surface. 'DST' = Data Storage Tag fitted. 'Acoustic' = acoustic tag was fitted, if the Y is coloured red, then this tag was detected by the FOL array.

Date	Skate Id	Tl (Cm)	Dw (Cm)	Sex	Dst	Acoustic	Tagging Location	Days Detected
03/03/2016	1	213	170	F	Y		FOL	
03/03/2016	2	211	159	F	Y		FOL	
03/03/2016	3	201	152	M	Y		FOL	
03/03/2016	4	180	137	M	Y		FOL	
03/03/2016	5	203	152	F	Y		FOL	
03/03/2016	**6**	203	160	F	Y		FOL	
07/03/2016	7	198	155	M	Y	Y	FOL	
07/03/2016	8	221	168	F	Y	Y	FOL	237
09/03/2016	9	109	79	F	Y	Y	FOL	20
09/03/2016	10	221	170	F	Y	Y	FOL	23
09/03/2016	11	208	165	F	Y	Y	FOL	
10/03/2016	12	175	137	M	Y	Y	FOL	
13/03/2016	**13**	174	135	F	Y	Y	FOL	201
13/03/2016	**14**	185	137	F	Y	Y	FOL	35
14/03/2016	**15**	180	140	F	Y	Y	FOL	25
14/03/2016	16	107	79	M	Y	Y	FOL	
14/03/2016	**17**	188	146	M	Y	Y	FOL	41
14/03/2016	18	206	155	F	Y	Y	FOL	6
14/03/2016	**19**	155	119	F	Y	Y	FOL	17
15/03/2016	**20**	155	114	F	Y	Y	FOL	24
15/03/2016	21	198	155	M	Y	Y	FOL	5
15/03/2016	22	213	163	F	Y	Y	FOL	33
15/03/2016	23	108	75	M	Y	Y	FOL	1
15/03/2016	**24**	201	155	F	Y	Y	FOL	40
15/03/2016	25	208	163	F	Y	Y	FOL	298
16/03/2016	26	160	114	F	Y	Y	FOL	87
16/03/2016	**27**	191	142	M	Y	Y	FOL	76
16/03/2016	**28**	160	130	F	Y	Y	FOL	165
16/03/2016	**29**	193	145	M	Y	Y	FOL	38
16/03/2016	30	185	147	M	Y	Y	FOL	22
16/03/2016	**31**	206	160	F	Y	Y	FOL	1
16/03/2016	**32**	196	150	M	Y	Y	FOL	47
16/03/2016	33	160	118	F	Y	Y	FOL	8
16/03/2016	**34**	198	149	M	Y	Y	FOL	4
17/03/2016	**35**	135	100	F	Y	Y	FOL	222
17/03/2016	**36**	213	170	F	Y	Y	FOL	168
17/03/2016	37	213	165	F	Y	Y	FOL	44
17/03/2016	**38**	206	160	F	Y	Y	FOL	77
17/03/2016	**39**	196	149	M	Y		FOL	
17/03/2016	40	226	175	F	Y		FOL	
01/09/2016	**52**	136	100	M	Y	Y	FOL	25
01/09/2016	**53**	156	115	M	Y	Y	FOL	89
01/09/2016	**54**	157	117	F	Y	Y	FOL	51
22/09/2016	**55**	177	139	M	Y	Y	FOL	10
22/09/2016	**56**	178	142	M	Y	Y	FOL	13

4.1.1 Acoustic

In total:

- 35 of the 41 (85%) skate were acoustically detected (Fig. 7 & 8) by the Firth of Lorn array.
- 21 female (95%) and 12 male (80%) tagged in the Firth of Lorn were detected by the Firth of Lorn array.
- No skate were detected in Loch Etive. One of the four skate tagged in the Sound of Jura was detected by the Firth of Lorn array.

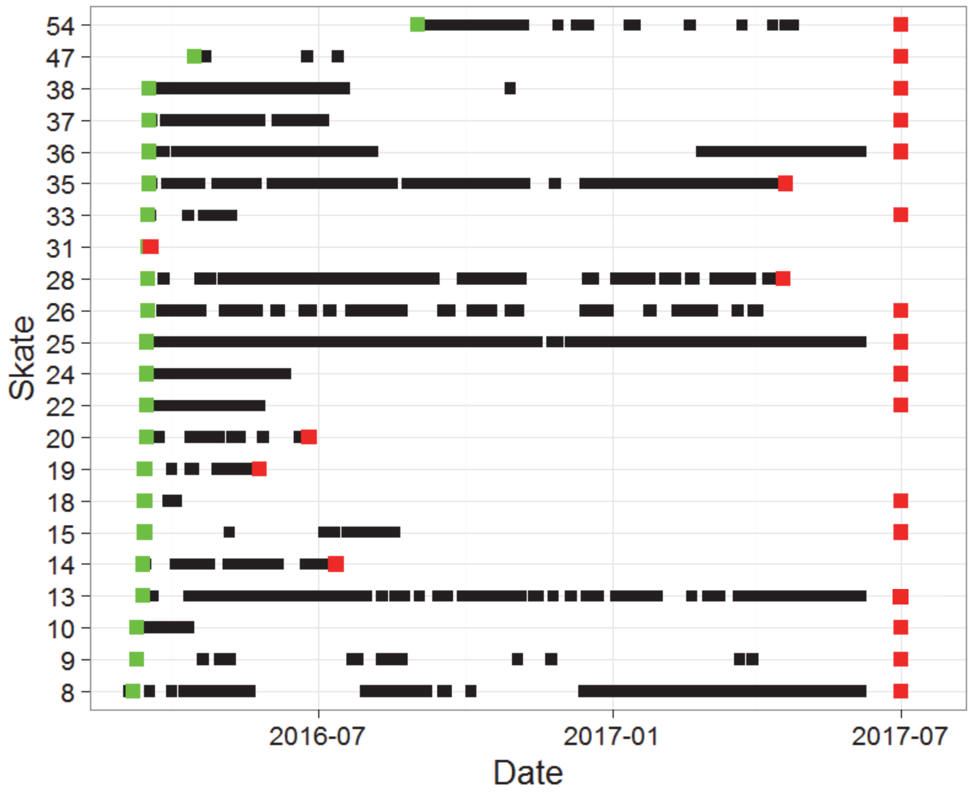

Figure 7. Detection plot of female skate in the Loch Sunart to the Sound of Jura MPA. Black marks show detections while green squares show tagging date and red squares show the date when the tag was removed. In many cases, it is unknown if a tag was removed or the skate had moved out of the area and so the tag removal data is shown as the same date the last receiver was removed (27/06/2017).

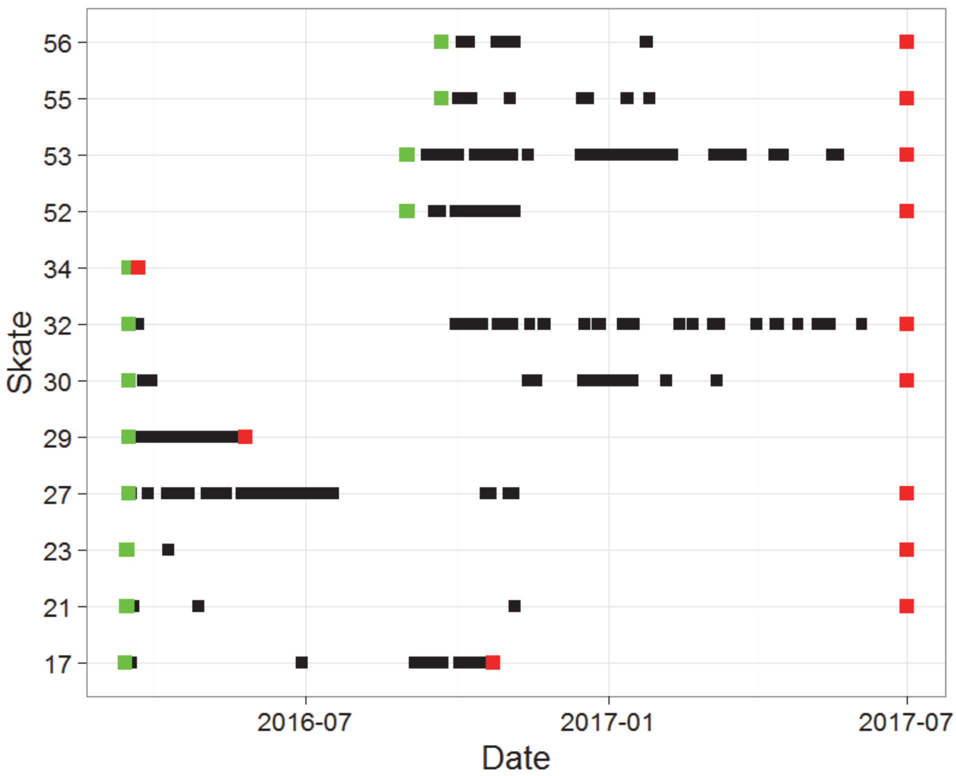

Figure 8. Detection plot of male skate in the Loch Sunart to the Sound of Jura MPA. Black marks show detections while green squares show tagging date and red squares show the date when the tag was removed. In many cases, it is unknown if a tag was removed or the skate has moved out of the area and so the tag removal data is shown as the same date the last receiver was removed (27/06/2017).

Females showed higher levels of usage of the area within range of the acoustic array, with a higher average number of days (84.86) detected than males (30.92) (Fig. 9 & Table 5). Some females showed almost continual residency within the detection range of the array with four female skate being detected over 200 days. Only two males were detected for longer than 50 days. There was no apparent relationship between the size of skate, either male nor female, and number of days detected. The proportion of tagged skate that continued to be detected decreased over time. In females, the proportion of detected skate decreased from 90% to 40% between March and September. It remained between 30-40% between September 2016 and March 2017. From March until the end of the project, the proportion of detected females dropped to 20% (Fig. 10). The proportion of tagged male skate detected started lower than for females at 65%. The proportion of males detected decreased to 0% in July 2016. The second tagging event in September 2016 increased the proportion of detected tagged males to 60%. This steadily decreased to 15% at the end of the project (Fig. 10).

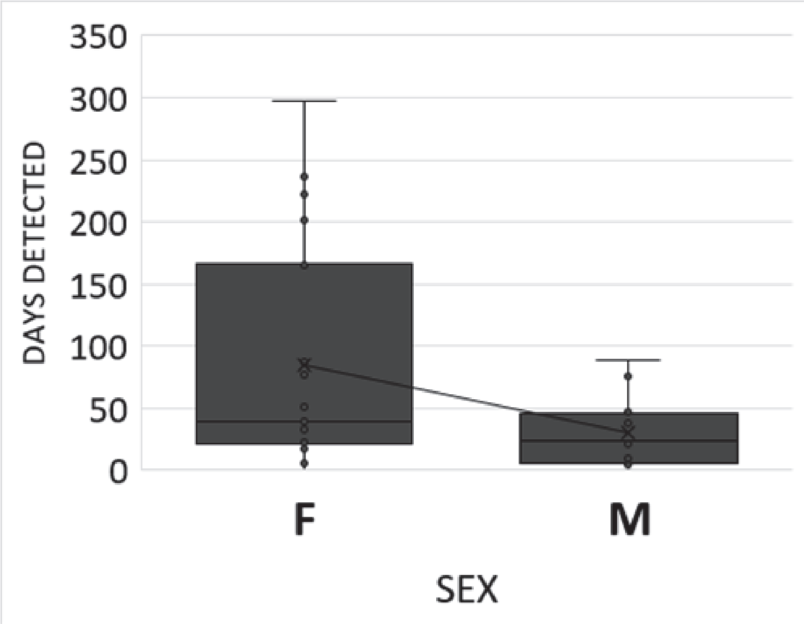

Figure 9. Box plot of days detected of skate tagged within the MPA split into gender

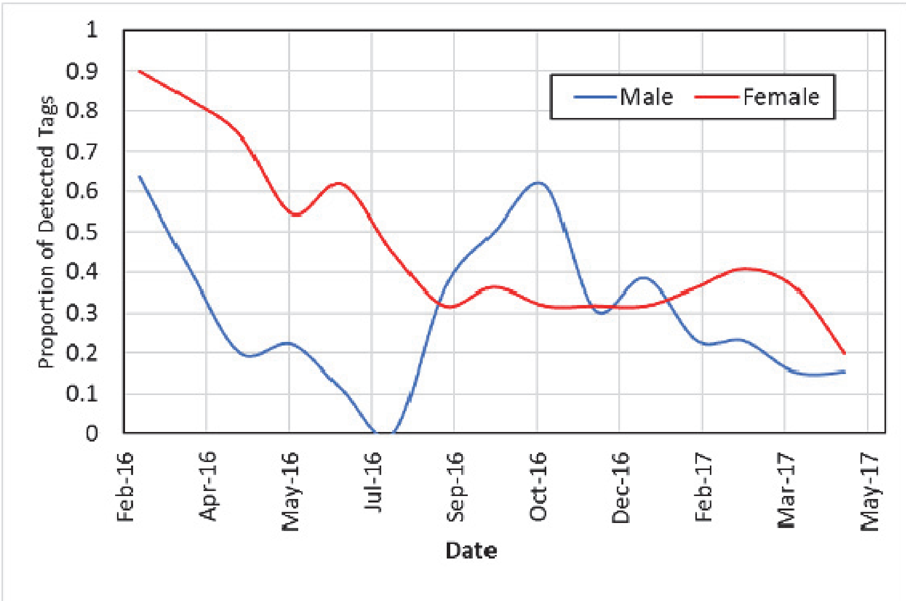

Figure 10. Proportion of tagged skate detected by the Firth of Lorn array split into gender

Table 5. Number of days' individual skate were detected by the acoustic array in the MPA split into gender. Average number of days, minimum number of days (not including skate not detected) and maximum number of days detected.

Sex	Average	Min	Max
M	30.92	1	89
F	84.86	1	298

4.1.2 Data Storage Tag records

Over the course of the project, 28 (44%) DSTs were returned. Data records were checked against acoustic detection and only DSTs that had deployment times of more than one month and associated acoustic detections (13 individuals) are reported here as these records are known to have occurred from within the MPA. Depths occupied while within the MPA were, on average, between 100 – 150 m. Between October 2016 and March 2017, it appears that skate make regular movement between surface waters (<10 m) and water depths of approximately 200 m. Over this time period, the average depth occupied decreased to a minimum of 47 m during January 2017 for one female skate (ID= 28) and 49 m in December 2016 for one male skate (ID= 27). This was not the case for all skate over this time with one female (ID=35) maintaining an average depth of 113–136 m between March 2016 – April 2017. See Figs. 11 - 22 for boxplots of depths recorded by all returned DSTs while present within range of the Firth of Lorn array.

For all boxplots, the median of the data is shown by the horizontal line in the centre of the box; the upper and lower quartiles (25,75%) are shown by the lower and upper edges of the central box; the minimum and maximum values recorded (excluding outliers which are unusually high or low values compared to the rest of the data, displayed by black points) are shown by the solid vertical lines above and below the central box. Depth data smoothed to a seven-day moving average are displayed in Annex 1. The maximum depth recorded while in the range of the acoustic receivers was 222 m.

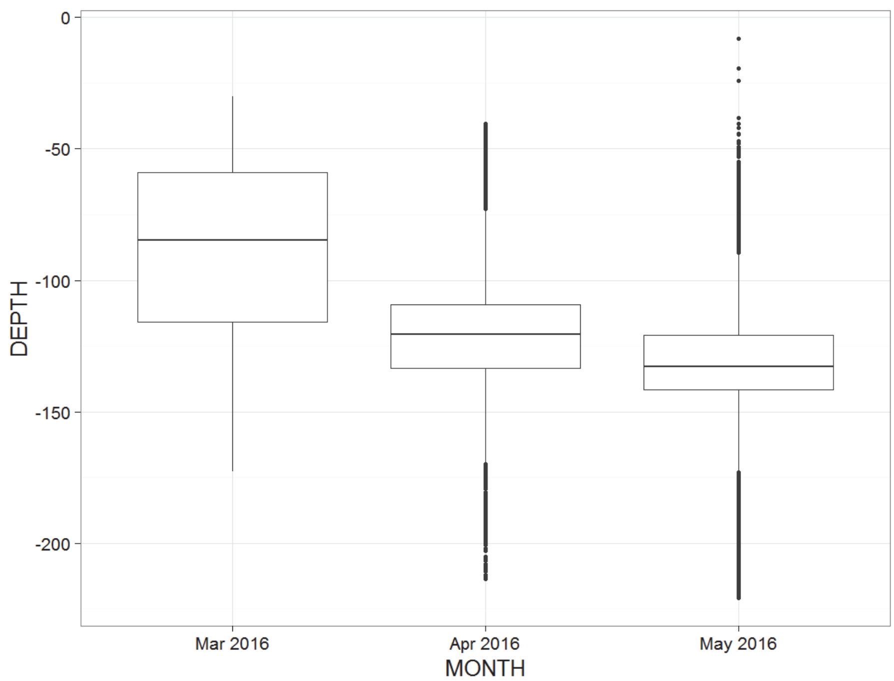

Figure 11. Boxplot of depths used by skate 38 within the MPA based on 32 days detection over 63 days deployment.

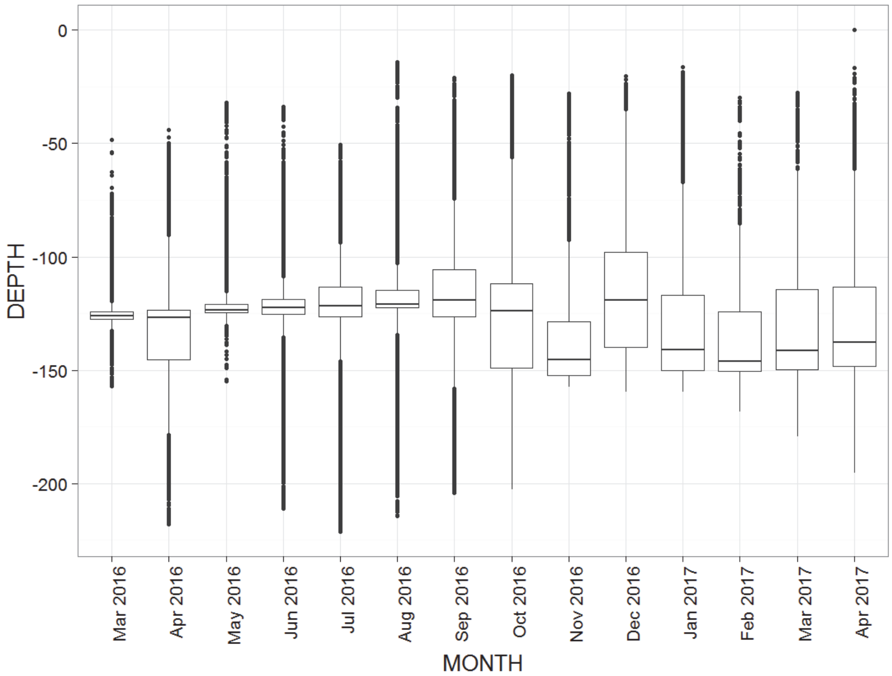

Figure 12. Boxplot of depths used by skate 35 within the MPA based on 222 days detection over 400 days deployment

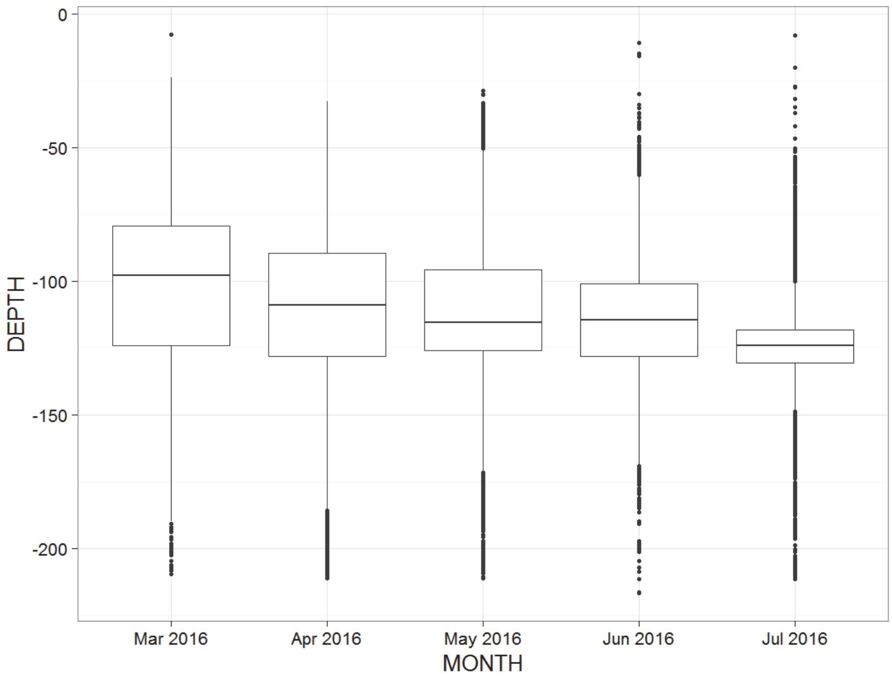

Figure 13. Boxplot of depths used by skate 36 within the MPA based on 72 days detection over 119 days deployment

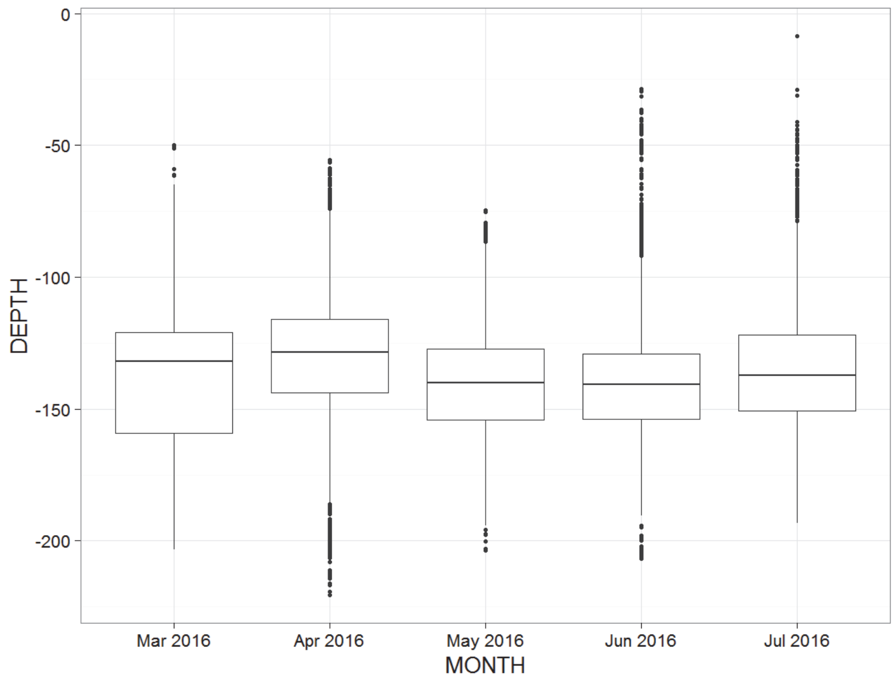

Figure 14. Boxplot of depths used by skate 27 within the MPA based on 66 days detection over 120 days deployment

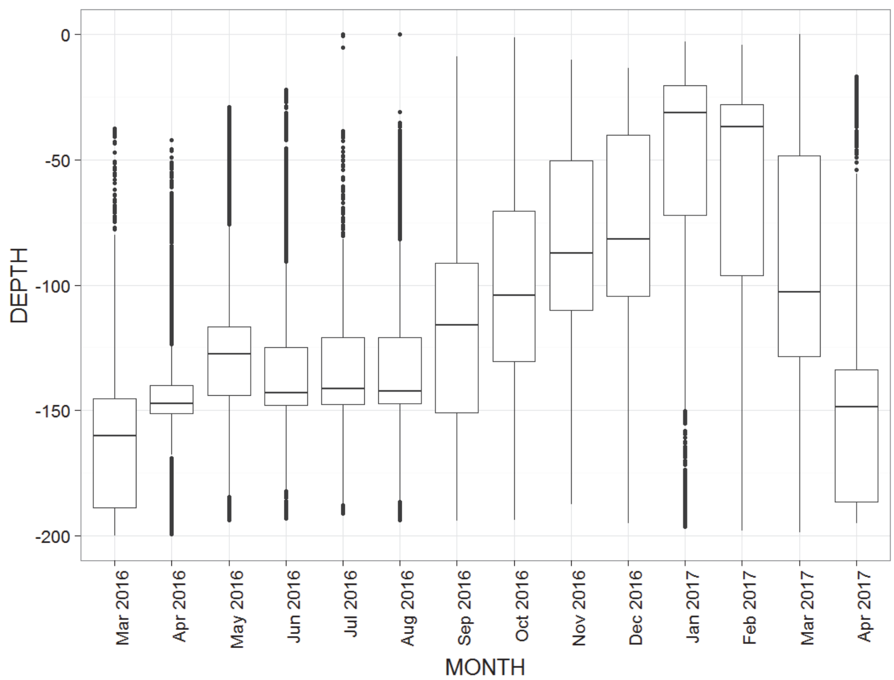

Figure 15. Boxplot of depths used by skate 28 within the MPA based on 165 days detection over 400 days deployment

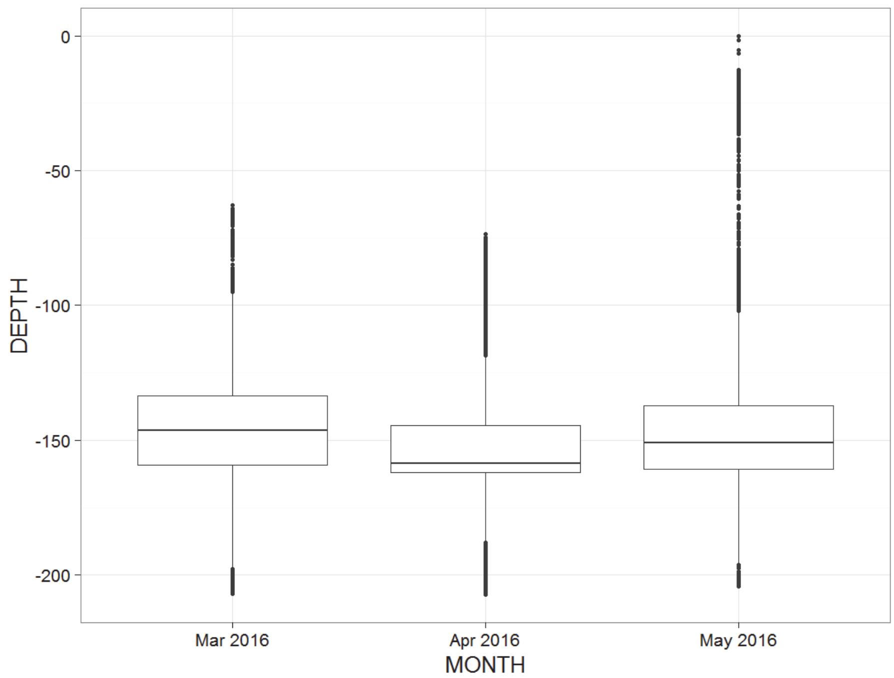

Figure 16. Boxplot of depths used by skate 29 within the MPA based on 38 days detection over 72 days deployment

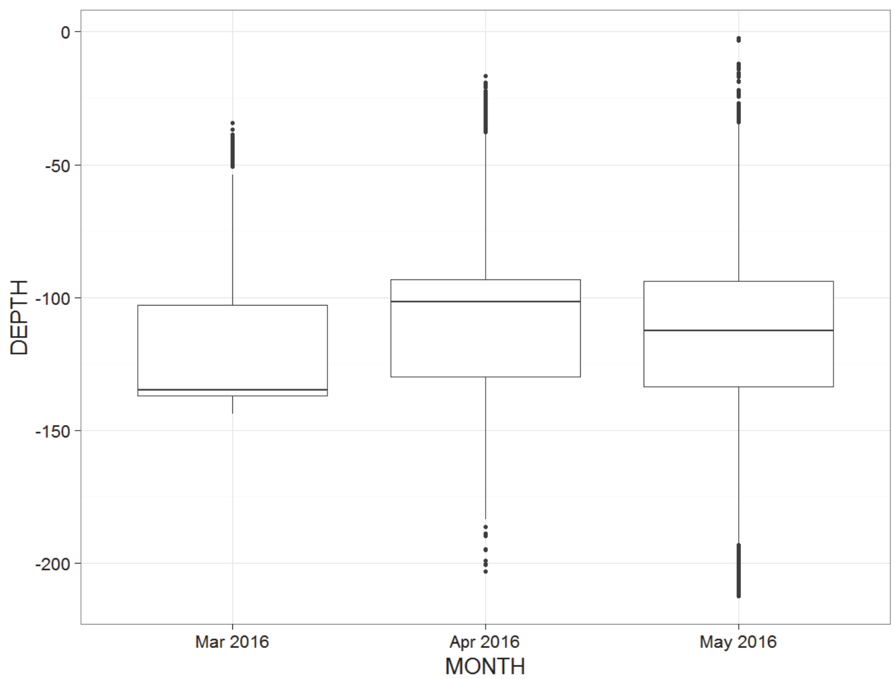

Figure 17. Boxplot of depths used by skate 19 within the MPA based on 17 days detection over 209 days deployment

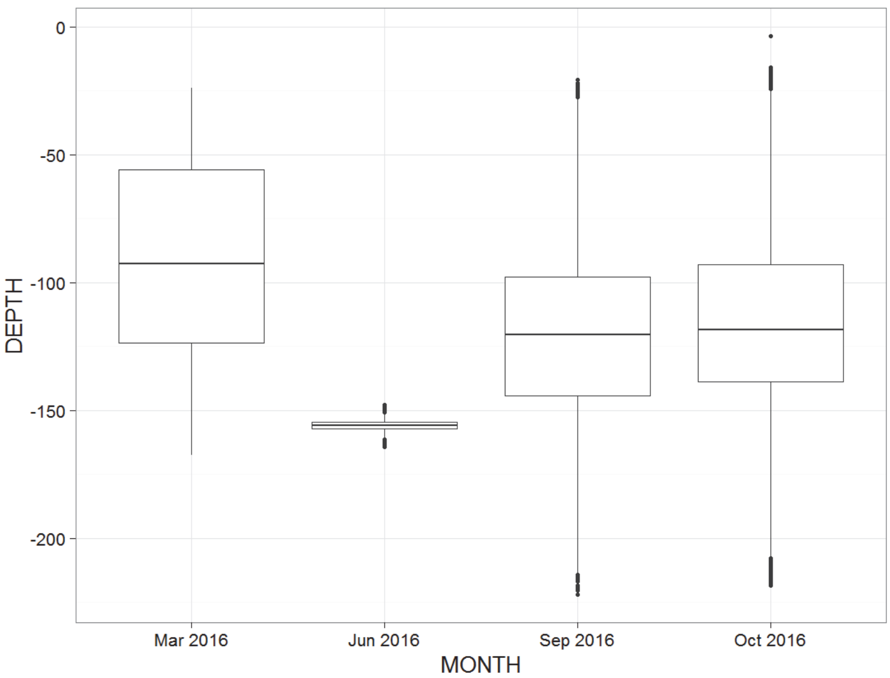

Figure 18. Boxplot of depths used by skate 17 within the MPA based on 41 days detection over 224 days deployment

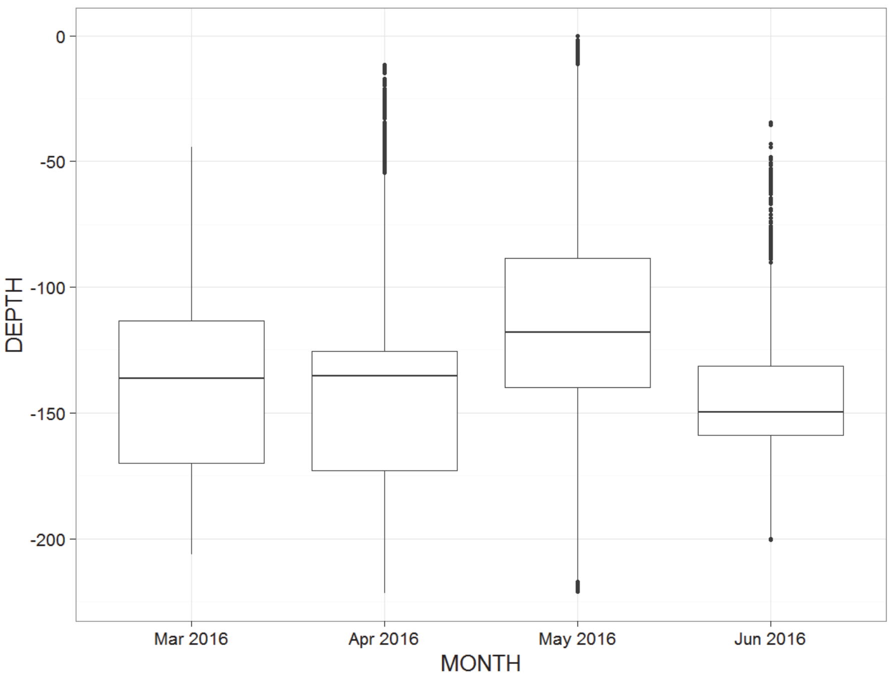

Figure 19. Boxplot of depths used by skate 20 within the MPA based on 24 days detection over 492 days deployment

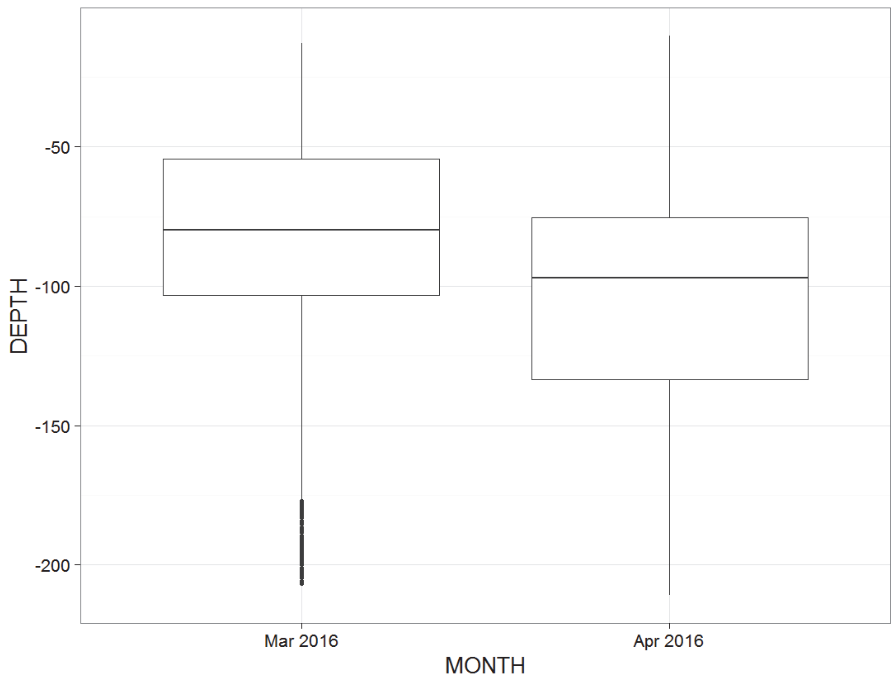

Figure 20. Boxplot of depths used by skate 24 within the MPA based on 24 days detection over 46 days deployment

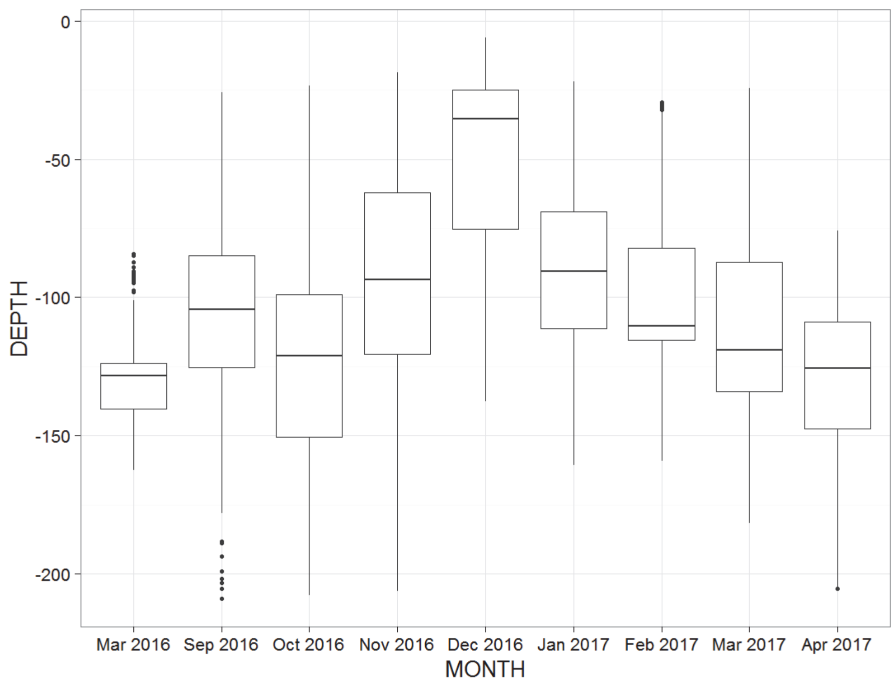

Figure 21. Boxplot of depths used by skate 32 within the MPA based on 39 days detection over 402 days deployment

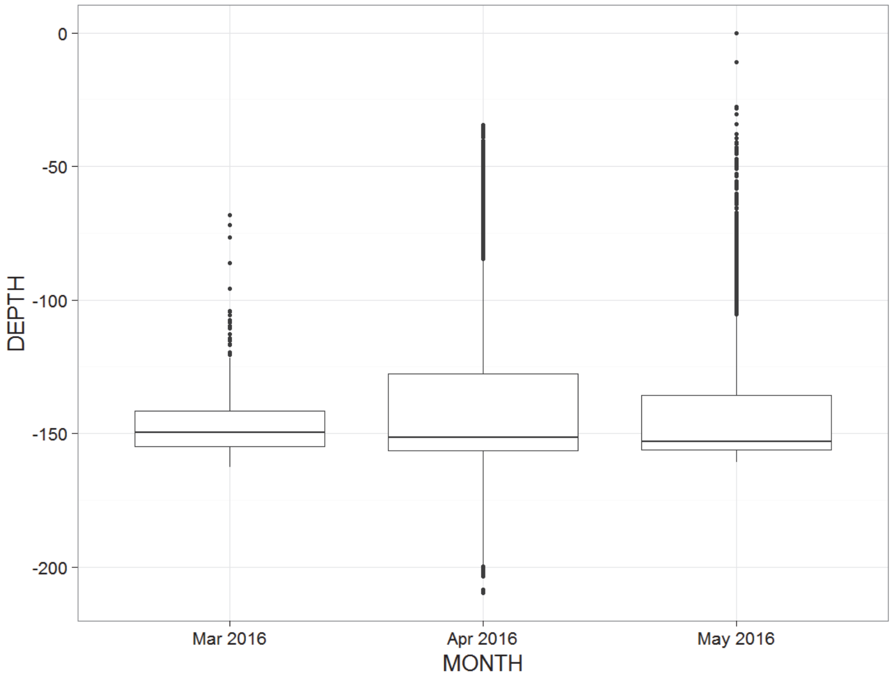

Figure 22. Boxplot of depths used by skate 13 within the MPA based on 36 days detection over 77 days deployment

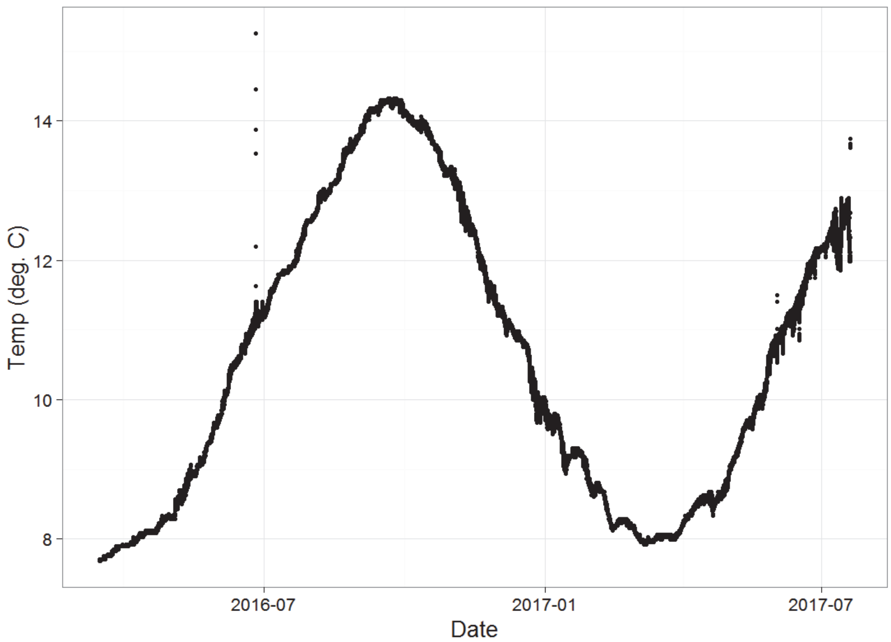

Figure 23. Example of a temperature plot from a Data Storage Tag deployed on a skate (Skate 20).The temperature anomaly on the 25th June 2016 can be explained by a recapture event with the skate being landed on the deck of a boat and being subjected to higher temperatures

Skate did not actively move between different temperatures over short time periods. The exception to this were recapture events, which brought skate through different temperatures to the surface. Skate were subject to seasonal temperature changes, with tagged skate experiencing temperatures between 7.5 °C in March 2016 and 14.5 °C in September 2016. Fig. 23 shows a typical long-term DST temperature record, all other DST records showed similar temperature patterns. The temperature anomaly displayed on Fig. 23 show a recapture event when the skate was landed on the deck of a boat.

4.2 Spurdog

A total of 59 spurdog were tagged with acoustic tags; eight in the Firth of Lorn (Fig. 3) between 9 – 17th March 2016 (all male), 42 in Loch Etive (Fig. 5) up-stream from the Falls of Lora between the 20th - 21st July 2016, (20 female and 22 male), and 9 in Loch Etive downstream of the Falls of Lora on the 22nd July 2017 (all female). See Tables 3 and 4 for details of tagged spurdog. Five spurdog in the Firth of Lorn were also tagged with DSTs, but none of these have been returned. Details of spurdog tagged are displayed in Tables 3 & 4.

Table 3. Details of spurdog tagged in the Falls of Lora (FALLS) and the Firth of Lorn (FOL). TL = Total Length in cm, ID = Identification number of the spurdog relevant to all other figures and text in this document. If the ID number is coloured red, then the tag was detected by at least one receiver from the Etive or Firth of Lorn acoustic array. Underlining shows spurdog tagged with Data Storage Tags.

Date	Tagging Location	Sex	Tl (Cm)	Id	Days Detected
22/07/2016	FALLS	F	80	43	
22/07/2016	FALLS	F	97	**44**	5
22/07/2016	FALLS	F	84.5	45	
22/07/2016	FALLS	F	81	**46**	2
22/07/2016	FALLS	F	79.5	**47**	11
22/07/2016	FALLS	F	85.5	**48**	99
22/07/2016	FALLS	F	86.5	**49**	59
22/07/2016	FALLS	F	76.5	50	
22/07/2016	FALLS	F	99.5	**51**	127
09/03/2016	FOL	M	73	**52**	83
09/03/2016	FOL	M	84	**53**	18
10/03/2016	FOL	M	82	**54**	56
14/03/2016	FOL	M	80	**55**	2
15/03/2016	FOL	M	83	**56**	
15/03/2016	FOL	M	74	57	106
17/03/2016	FOL	M	72	**58**	
17/03/2016	FOL	M	83	59	

Table 4. Details of spurdog tagged in Loch Etive. TL = Total Length in cm, ID = Identification number of the spurdog relevant to all other figures and text in this document. If the ID number is coloured red, then the tag was detected by at least one receiver from the Etive or Firth of Lorn acoustic array.

Date	Tagging Location	Sex	Tl (Cm)	Id	Days Detected
20/07/2016	ETV	F	70	**1**	300
20/07/2016	ETV	F	70	**2**	262
20/07/2016	ETV	F	65	**3**	270
20/07/2016	ETV	M	72	**4**	266
20/07/2016	ETV	F	61	**5**	328
20/07/2016	ETV	F	65	**6**	256
20/07/2016	ETV	F	79	**7**	293
20/07/2016	ETV	F	32	**8**	8
20/07/2016	ETV	F	67	**9**	325
20/07/2016	ETV	F	68	**10**	293
20/07/2016	ETV	F	64.5	**11**	266
20/07/2016	ETV	M	34	**12**	1
20/07/2016	ETV	M	33	13	
20/07/2016	ETV	F	62	**14**	292
20/07/2016	ETV	M	72	**15**	327
20/07/2016	ETV	F	59	**16**	176
20/07/2016	ETV	M	62	**17**	305
20/07/2016	ETV	F	62	**18**	169
20/07/2016	ETV	M	74.5	**19**	257
20/07/2016	ETV	F	66.5	**20**	272
20/07/2016	ETV	M	72	**21**	136
21/07/2016	ETV	F	49.5	**22**	11
21/07/2016	ETV	M	44	**23**	4
21/07/2016	ETV	M	72.5	**24**	361
21/07/2016	ETV	M	45	**25**	5
21/07/2016	ETV	M	65	**26**	365
21/07/2016	ETV	F	73.5	**27**	330
21/07/2016	ETV	M	70	**28**	359
21/07/2016	ETV	M	74	**29**	314
21/07/2016	ETV	M	65	**30**	362
21/07/2016	ETV	M	63	**31**	362
21/07/2016	ETV	M	67	**32**	354
21/07/2016	ETV	M	65	**33**	356
21/07/2016	ETV	M	75	**34**	354
21/07/2016	ETV	M	70	**35**	365
21/07/2016	ETV	M	60	**36**	240
21/07/2016	ETV	F	63	**37**	354
21/07/2016	ETV	M	72	**38**	364
21/07/2016	ETV	F	69	**39**	364
21/07/2016	ETV	F	62	**40**	341
21/07/2016	ETV	F	68	**41**	344
21/07/2016	ETV	M	67.5	**42**	365

The entire receiver array, including units in the Firth of Lorn and Loch Etive detected:

- 41 (98%) spurdog tagged in Loch Etive.
- 6 (66%) spurdog tagged at the Falls of Lora.
- 6 (75%) spurdog tagged in the Firth of Lorn.

The Loch Etive array (all receivers upstream from the Falls of Lora) detected:

- 41 (98%) spurdog tagged in Loch Etive.
- 3 (33%) spurdog tagged at the Falls of Lora.
- 1 (12.5%) spurdog tagged in the Firth of Lorn.

4.2.1 Firth of Lorn

Spurdog tagged in the Firth of Lorn were detected by the Firth of Lorn array until August 2016 when all detections ceased. Detections started again in November 2016 and continued sporadically until June 2017. Of the spurdog tagged downstream of the Falls of Lora, one was detected by the Firth of Lorn array in November 2016 and a further two were detected by the Firth of Lorn array between February and April 2017. Two spurdog tagged in the loch (both female) were detected by the Firth of Lorn array, one briefly in November, the other in the second half of June 2017 (Figs. 24 & 25).

4.2.2 Loch Etive

Spurdog tagged in Loch Etive spent most of the time within range of the receivers in the loch over the course of the year with the average number of days being 277 for females and 258 for males. In total, 95% of the spurdog tagged in Loch Etive were detected for more than 250 days in the loch (Fig 25, Table 6). Three spurdog tagged beyond the Falls of Lora were detected regularly in Loch Etive between October 2016 and June 2017, while another 3 were detected with less frequency in Loch Etive. Two female spurdog tagged in the Loch Etive were detected outside the loch, once in November 2016 and over several days in June 2017 (Figs. 24 & 25 – ID 3 & 8). Spurdog smaller than 50 cm total length had the lowest number of detections (0-11 days). There was no discernible difference in the number of days that the different sex classes were detected (Fig. 26). The proportion of tagged spurdog of both sexes detected in Loch Etive remained high between 80-100% for the duration of the project until March 2017. In March 2017, the proportion of tagged female spurdog detected decreased to 60% while the proportion of detected males remained at 80% (Fig. 27).

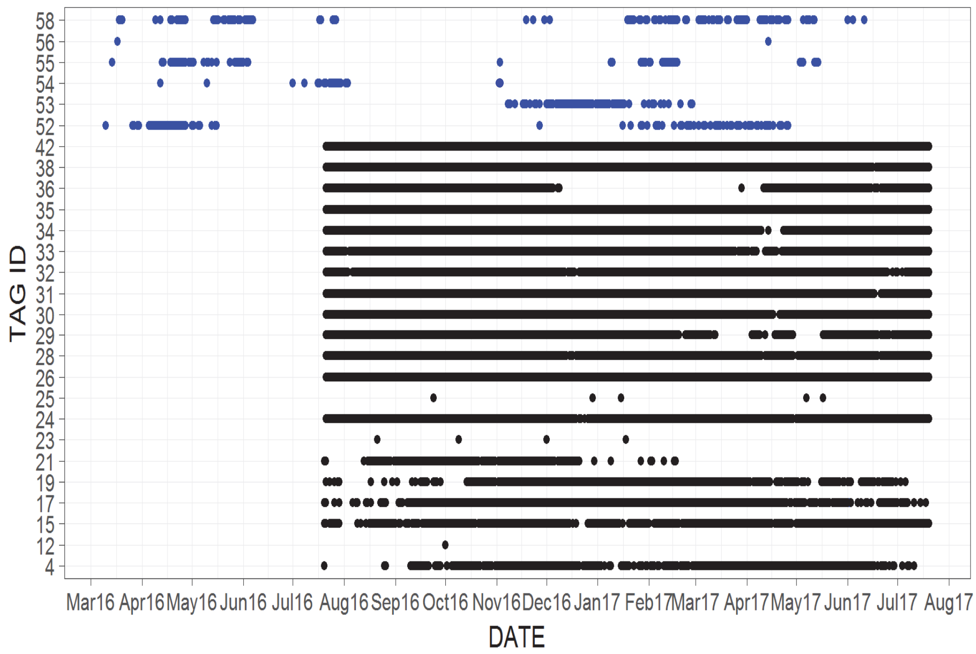

Figure 24. Male detections on all receivers. Marks in blue occurred outside Loch Etive, all receivers downstream from the Falls of Lora. TAG ID's 52 – 58 were tagged in the Firth of Lorn

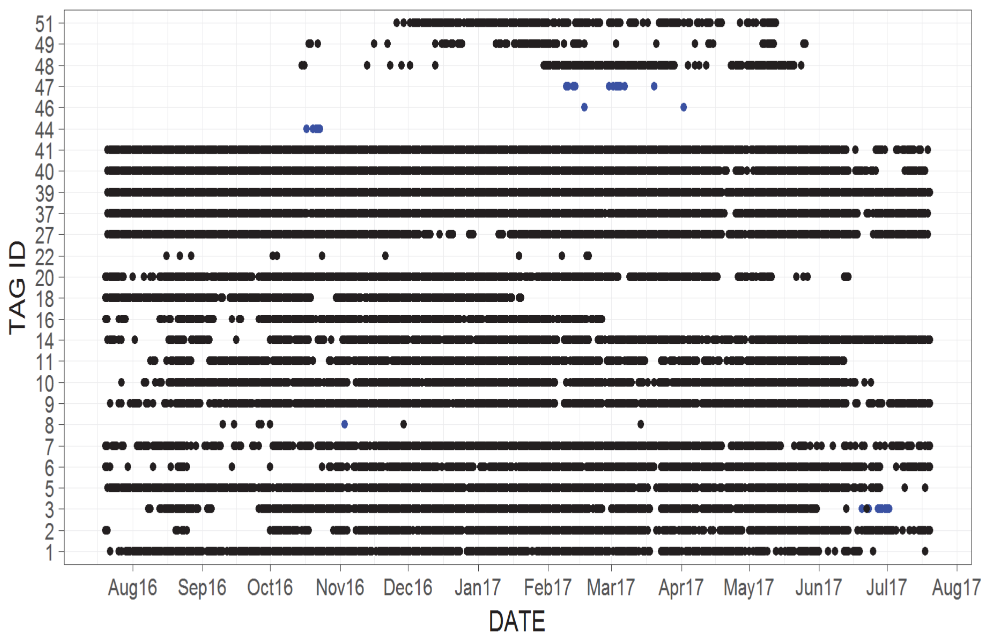

Figure 25. Female detections on all receivers. Marks in blue occurred outside Loch Etive, all receivers downstream from the Falls of Lora. TAG ID's 44 – 51 were tagged at the Falls of Lora.

Table 6. Number of days individual spurdog were detected by the acoustic array in Loch Etive split by gender. Average number of days, minimum number of days and maximum number of days detected

Sex	Number Of Days		
	Average	Min	Max
M	277.24	1	365
F	258.42	8	364

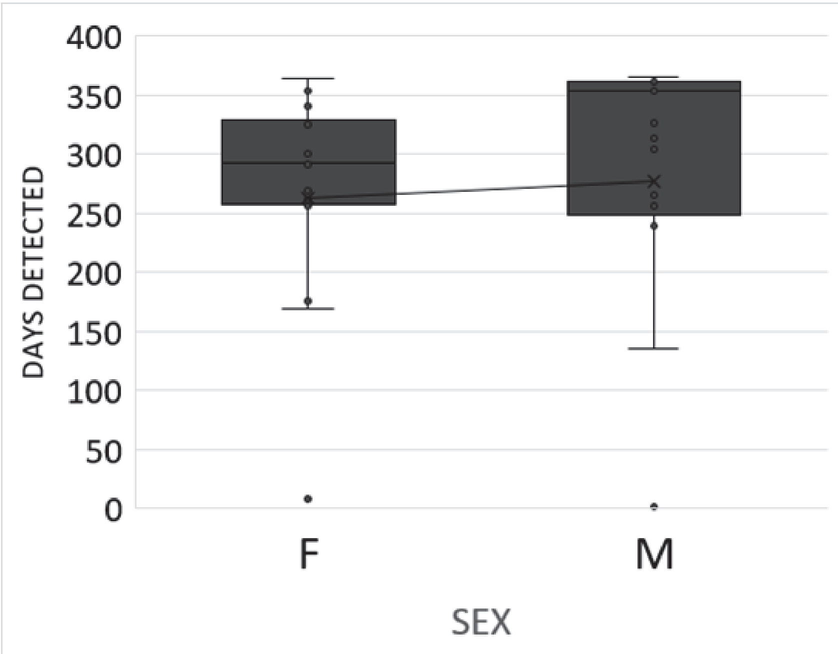

Figure 26. Box plot of days detected by the Loch Etive array of spurdog tagged within Loch Etive split by gender

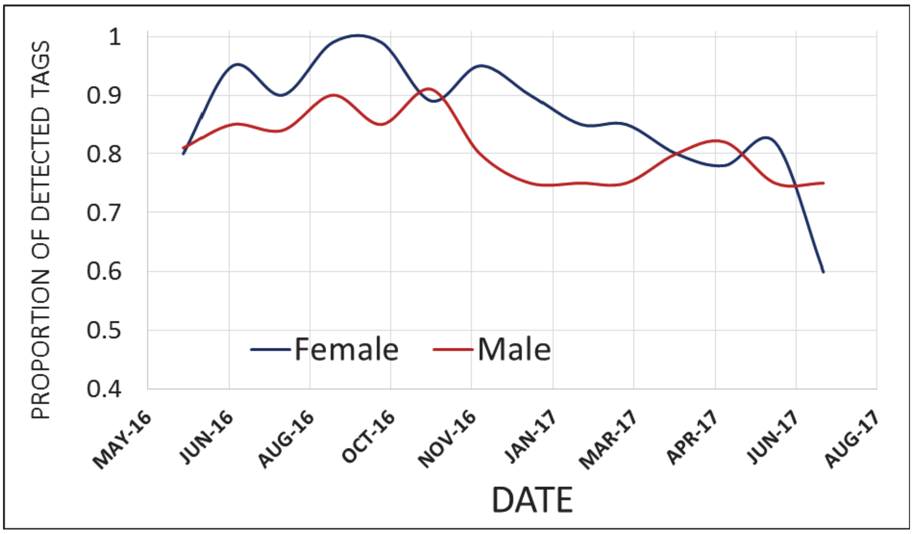

Figure 27. Proportion of spurdog tagged in Loch Etive, detected by the Loch Etive array.

5. DISCUSSION

5.1 Flapper skate

Females appear to make more use of the area within range of the Firth of Lorn array than males, with a higher number of days detected than males. A decrease in the proportion of males detected from tagging events in March 2016 and September 2016, to 0% and 15% respectively, suggests that males move into the area over October to March, but most appear to move away from May to August. On average, 40% of the females tagged appeared to be residential within or nearby the receiver detection range with continual detections over the course of the project. There were several male skate that, despite low numbers of days detected, did show detections over several months suggesting regular use of the area within receiver range. Mark/Recapture data already suggests repeated use of the area by male skate, yet the acoustic data is suggestive that there is a higher level of movement in males in comparison to females. It is important to note that approximately only 17% of the MPA was within detection range by the Firth of Lorn array (MPA = 720 km^2, 39 receivers with 1 km detection radius (3.14 km^2 per unit) = 122.5 km^2 total receiver coverage without taking overlap into account), so skate could still have been within the MPA but out of range of the receivers. Taking this and tag removal/shedding into account, it could be suggested that 40% is the minimum proportion of female skate showing signs of residency within the MPA and both males and females may be more present than the acoustic data suggests.

Some movement out of the MPA by female skate was shown with one DST being returned from Mallaig Bay over a year after deployment. This equates to a minimum swim distance of around 100 km (68 km straight-line). At this stage, we do not know what proportion of the skate show this transient behaviour as a lack of detections may also be accounted for by natural mortality, faulty tags, tags falling off or being removed and not returned to the project.

The depth ranges that skate occupy in the MPA show that between April and August, the skate prefer deeper water and mostly stay below 100 m. This may be in response to thermal stratification over the warmer summer months and an increase in sea surface temperatures. There is no evidence in the temperature data that skate move between different temperature regimes during vertical movements and they do not appear to use thermoclines to thermo-regulate as has been suggested in some elasmobranch species (Sims *et al.* 2006). In winter months when surface waters cool and are mixed by storms, the water column temperature becomes more uniform, this may allow skate with a preference for cooler water to move up into the shallower depths. The move to shallower water over winter months is unlikely to be in relation to egg-laying as both males and females undertook these movements. Neither is the movement likely to be for mating, even though both male and female fish undertaking this movement were sexually mature, since the fish remained in the shallower water for several months. It is possible that a seasonal preference for depth is related to prey distribution, however, without understanding the seasonal dietary composition of skate in the area, this cannot be tested currently.

5.2 Spurdog

The male spurdog tagged in the Firth of Lorn were detected by the Firth of Lorn array from March through to August when they moved beyond the detection range of the receivers. They then returned to the area around the Firth of Lorn array in November where they appeared to remain sporadically until June. Temporal occupancy appears to vary between individuals. Conversely, spurdog of both sexes displayed very high residency within Loch Etive, with most spurdog remaining within the loch all year, only two spurdog, both juvenile, tagged in Loch Etive were detected by the Firth of Lorn array. One of these was detected in Loch Etive sporadically before being detected in the Firth of Lorn in November. Following this, it moved back into Loch Etive. The second spurdog was detected regularly in Loch

Etive throughout the project until June 2017 when it moved out into the Firth of Lorn. These detections show a connection between Loch Etive and the Firth of Lorn, but this does not appear to be a regular link for the juvenile spurdog tagged in this study.

The receivers in Loch Etive only extended halfway up the upper basin, so it is possible that the smaller spurdog spent more time in the upper end of Loch Etive out of range. Due to the low number of detections, it is not possible to say if spurdog <50 cm spent much time in the Firth of Lorn, but the detections in Loch Etive do suggest that even if there is an outward movement into the Firth of Lorn, small spurdog maintain site fidelity to Loch Etive. There is some connectivity between the Falls of Lora and Loch Etive. The female spurdog tagged beyond the falls were detected by the Firth of Lorn array and the Loch Etive array, but no individual was detected by both arrays suggesting spurdog tagged at this site either moved up into the loch or out into the Firth of Lorn.

Maturity in NE Atlantic spurdog has been recorded as being reached when individuals are between 55-61 cm in males and 69 – 83 in females (Hammond & Ellis 2005, Stenberg 2005). Based on this, most of the spurdog tagged in Loch Etive would either be immature or early mature individuals. The presence of neonates and spurdog around 30 cm does suggest that the loch is, or at least is part of, a nursery ground for this species. The fact that all age classes of spurdog up to maturity can be found in Loch Etive further suggests that it may form a refuge for at least some maturing spurdog with adult animals apparently moving out at some point, as large spurdog are not found commonly in the loch (anecdotal evidence from anglers). There is evidence that mature animals do move back into the loch for periods of time to mate (Thorburn *et al.* 2015), but no evidence of this was found during this study.

5.3 Summary

Flapper skate (*Dipturus intermedius*)

- Tagged females displayed higher occupancy in the surveyed area of the MPA than males. The average number of days females remained in the surveyed area of the MPA over the course of the project (13 months) was 85, whereas for males it was 31. Four female skate were detected for over 200 days each. Only two males were detected for longer than 50 days. The proportion of tagged male skate detected was never higher than 70% and did decrease to 0% in one month.
- Skate mostly remain in water depths between 100 – 150 m over summer months (March – August) with some individuals having a larger depth range over winter months (September – February).

This project generated significant quantities of data. These are currently being used as part of the Movement Ecology of the Flapper skate project at the University of St Andrews. This project is due to be completed in October 2021. Part of the planned outputs from the Movement Ecology of the Flapper skate is a catalogue of skate data. This will be made publicly available after 2023 except for locations of skate capture which are considered to be commercially confidential.

Spurdog (*Squalus acanthias*)

- Both sexes have high residency in Loch Etive. 95% of tagged spurdog were detected in the loch for more than 250 days. There was no apparent difference in the length of residency between the sexes.
- The male spurdog tagged in the Firth of Lorn did show seasonal site fidelity to the Firth of Lorn with little interaction with Loch Etive. This is suggestive of another winter refuge beyond the detection range of any of the receivers.
- Where the movements of male and female spurdog could be compared, there were no discernible differences in movements between the sexes.
- There were low numbers of detections of spurdog smaller than 50 cm, there was a

suggestion that some individuals this size move into the Firth of Lorn for some part of the year.

This report represents a preliminary analysis of the significant quantities of data generated by this data. A project is currently being funded at University of St Andrews to further develop the analysis including geolocational models for the archival data. Part of the planned outputs is a catalogue of the spurdog data, this will be made publicly available after 2023 except for locations of spurdog capture which are considered to be commercially confidential.

5.4 Recommendations

This project has provided a valuable insight into the movements of both flapper skate and spurdog. It has also highlighted areas of research that would be of benefit to the management of both species.

Flapper skate

- Tagging of skate at multiple temporal and spatial distributions throughout the MPA would be of benefit. Due to the high diversity of residential and apparently transient animals within the MPA, this method of tagging would ensure that if there are different waves of skate that move into the MPA at different times, we would gain a better understanding of these movements.
- Long-term tagging of early life stages would provide information on the movement of varying life history stages and how this may change over time.
- Acoustic monitoring outside the boundaries of the MPA would provide information regarding the movement of skate beyond the MPA boundaries. This monitoring would probably be best with a regular survey rather than fixed receiver units.
- A model is being produced to analyse the full DST records to gain more insight into the movement of all returned DSTs outside the range of the acoustic array.

Spurdog

- Tagging of more adult spurdog with both acoustic and geolocational tags to determine the spatial range of adults that appear to use Loch Etive as a mating and nursery ground.
- Further investigations of neonatal spurdog movements using a higher resolution acoustic array, especially in the upper basin.
- Long-term acoustic tagging of spurdog in the loch to investigate the temporal duration of residency within the loch of all age and sex classes.

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ANNEX 1: DST RECORDS PER TAG

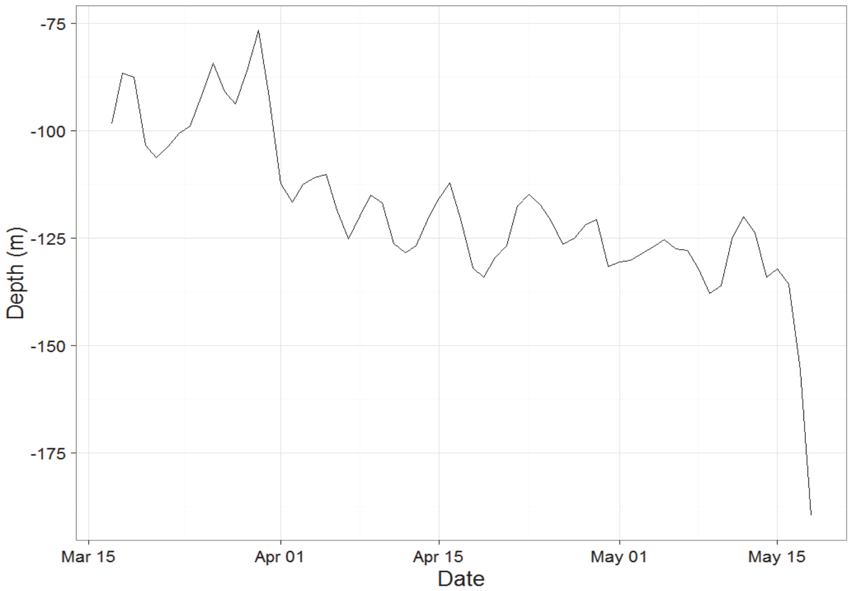

Figure A1. Depth data from skate 38; 63 days' deployment. Data is smoothed with 7 day moving average.

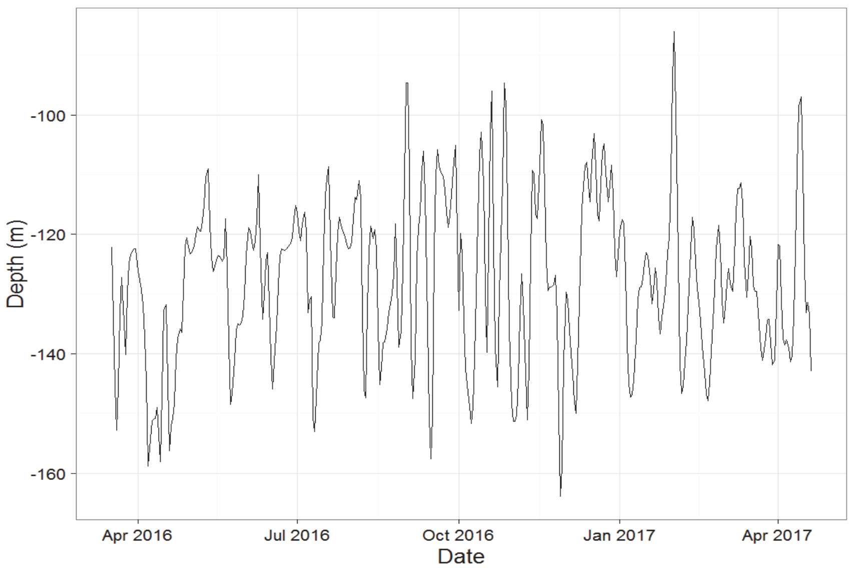

Figure A2. Depth data from skate 35; 400 days' deployment. Data is smoothed with 7 day moving average.

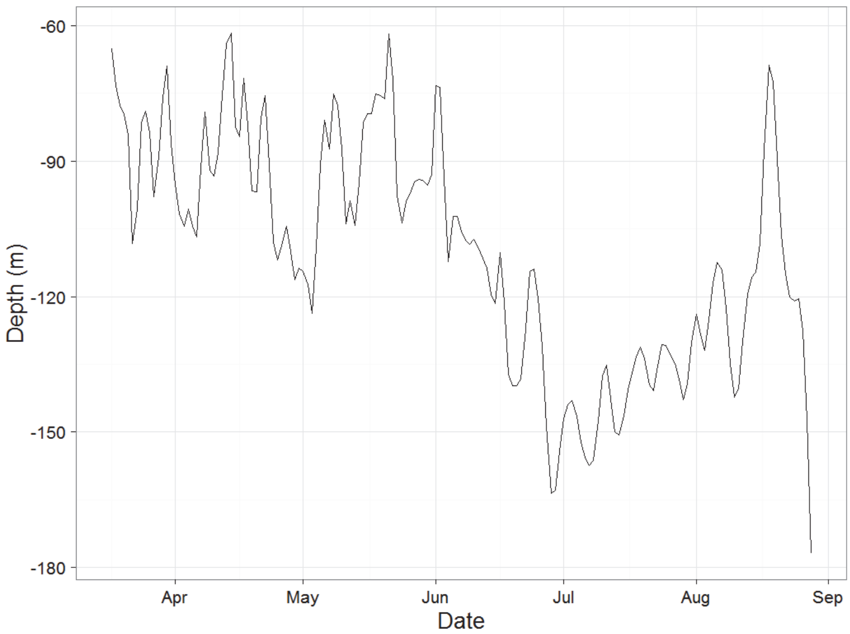

Figure A3. Depth data from skate 39; 165 days' deployment. Data is smoothed with 7 day moving average.

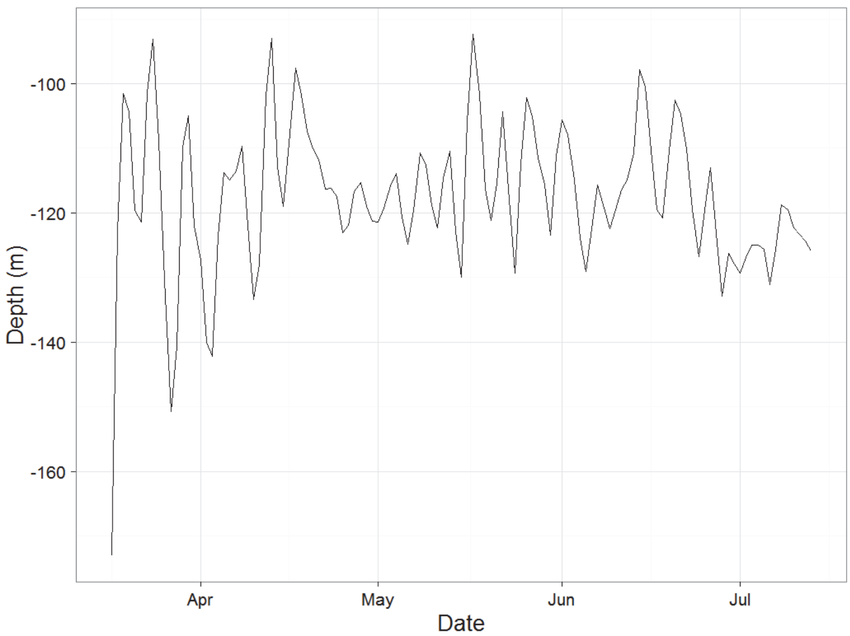

Figure A4. Depth data from skate 36; 119 days' deployment. Data is smoothed with 7 day moving average.

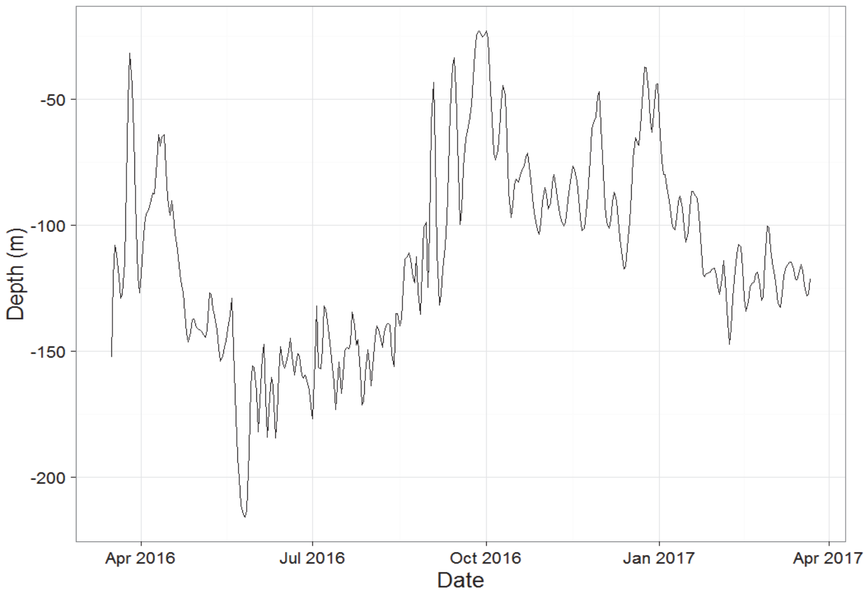

Figure A5. Depth data from skate 34; 372 days' deployment. Data is smoothed with 7 day moving average.

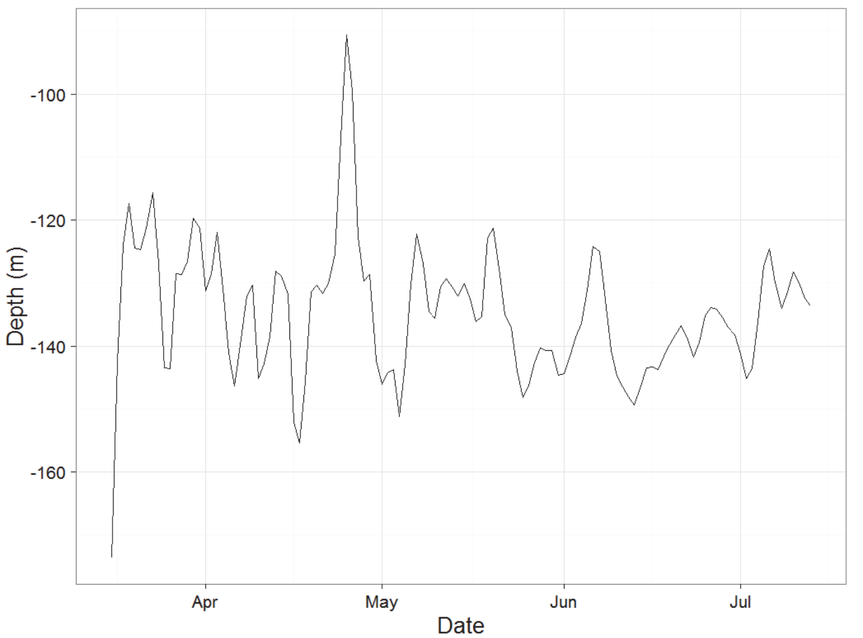

Figure A6. Depth data from skate 27; 120 days' deployment. Data is smoothed with 7 day moving average.

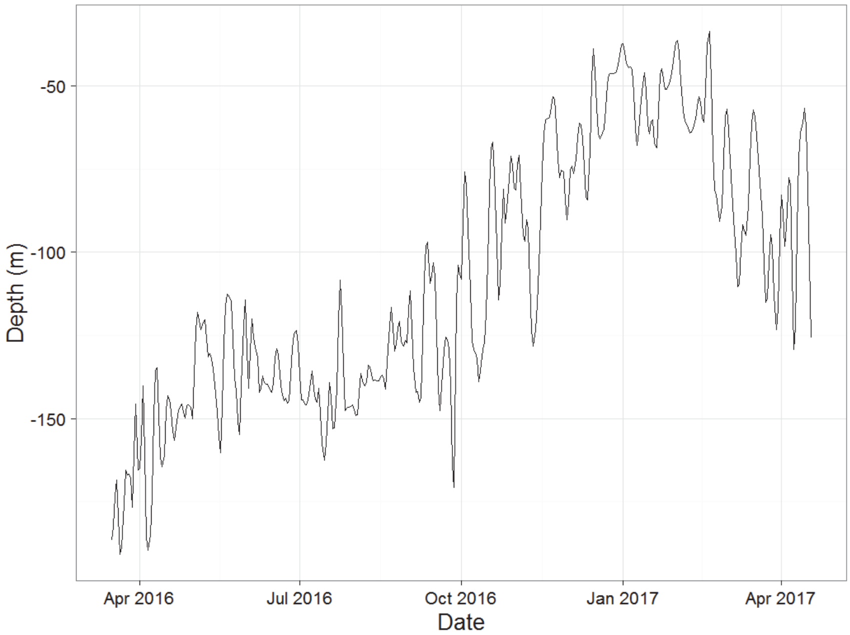

Figure A7. Depth data from skate 28; 400 days' deployment. Data is smoothed with 7 day moving average.

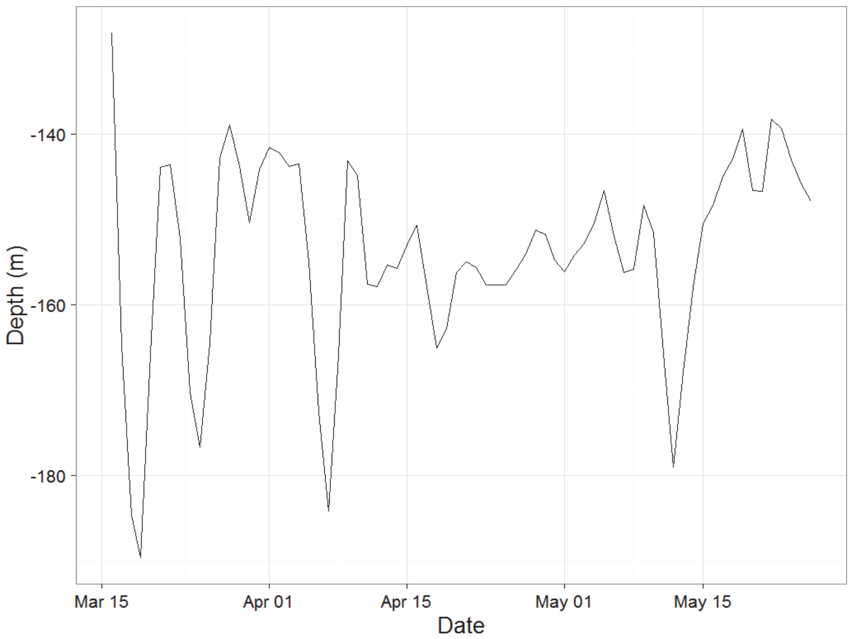

Figure A8. Depth data from skate 29; 72 days' deployment. Data is smoothed with 7 day moving average.

Figure A9. Depth data from skate 59; 15 days' deployment. Data is smoothed with 7 day moving average.

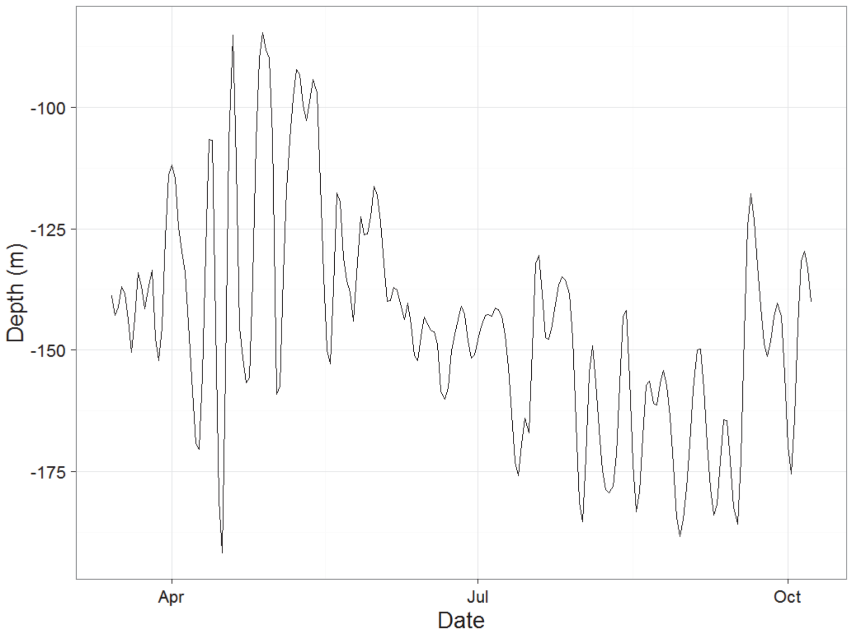

Figure A10. Depth data from skate 19; 209 days' deployment. Data is smoothed with 7 day moving average.

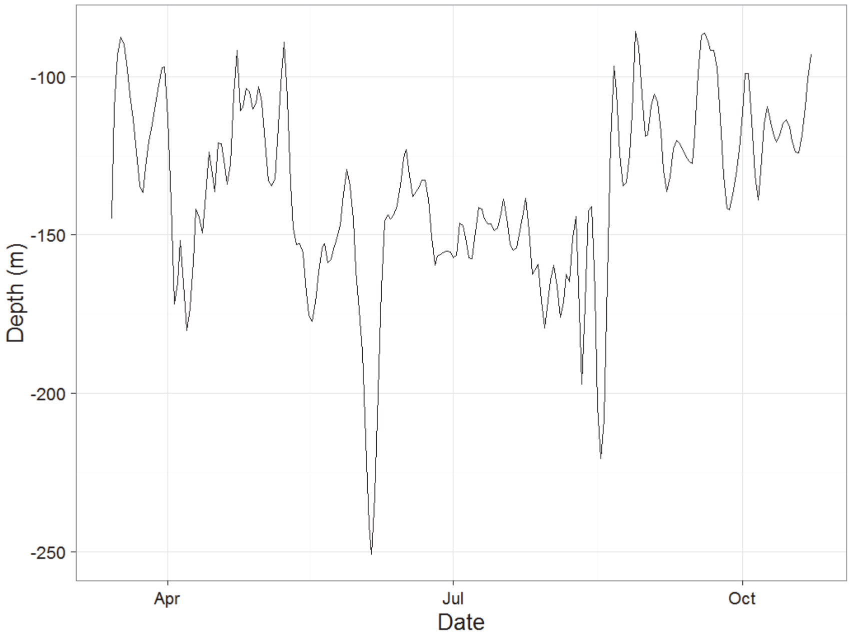

Figure A11. Depth data from skate 17; 224 days' deployment. Data is smoothed with 7 day moving average.

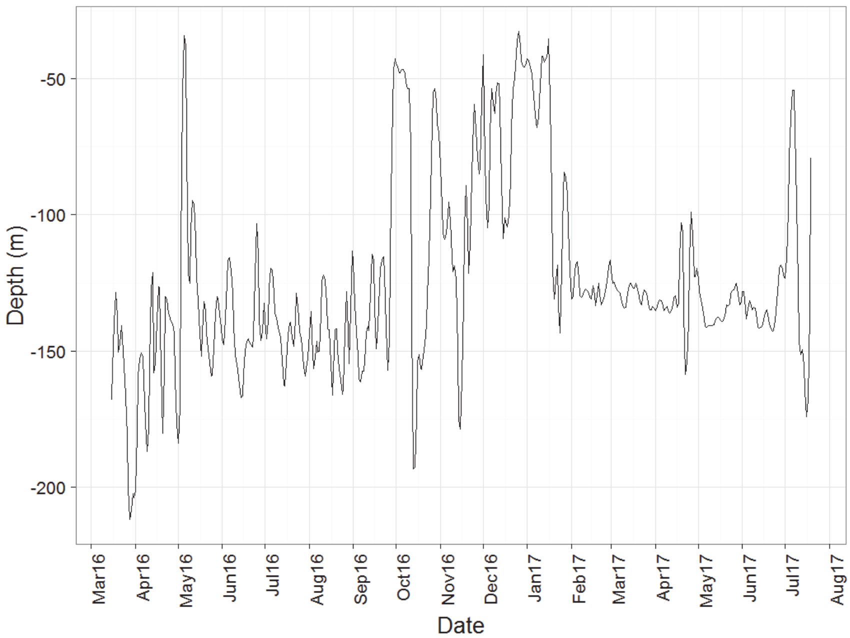

Figure A12. Depth data from skate 20; 492 days' deployment. Data is smoothed with 7 day moving average.

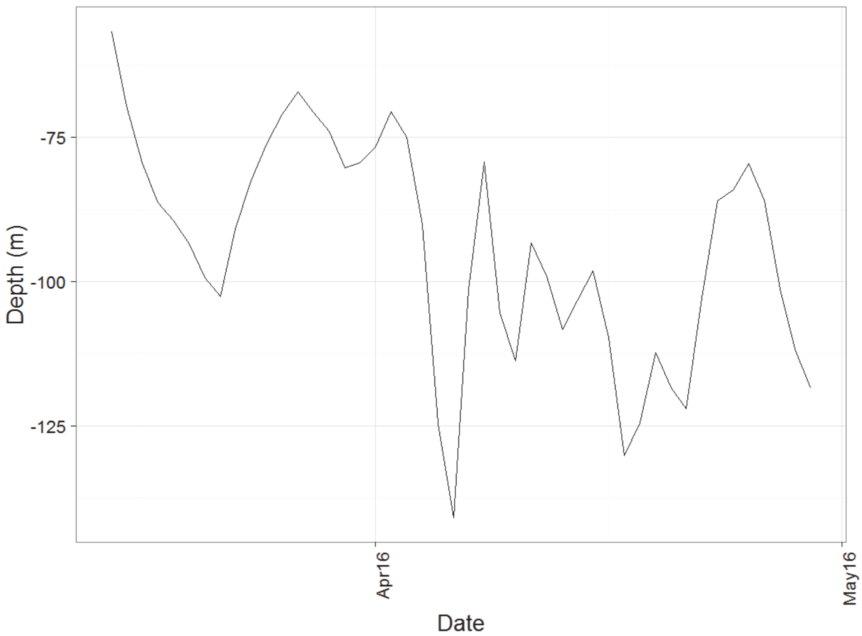

Figure A13. Depth data from skate 24; 46 days' deployment. Data is smoothed with 7 day moving average.

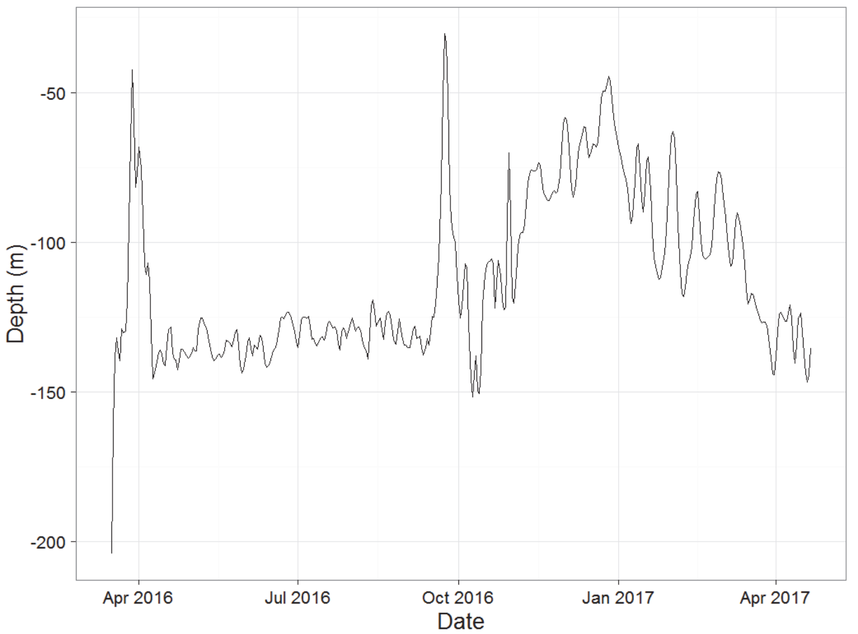

Figure A14. Depth data from skate 32; 402 days' deployment. Data is smoothed with 7 day moving average.

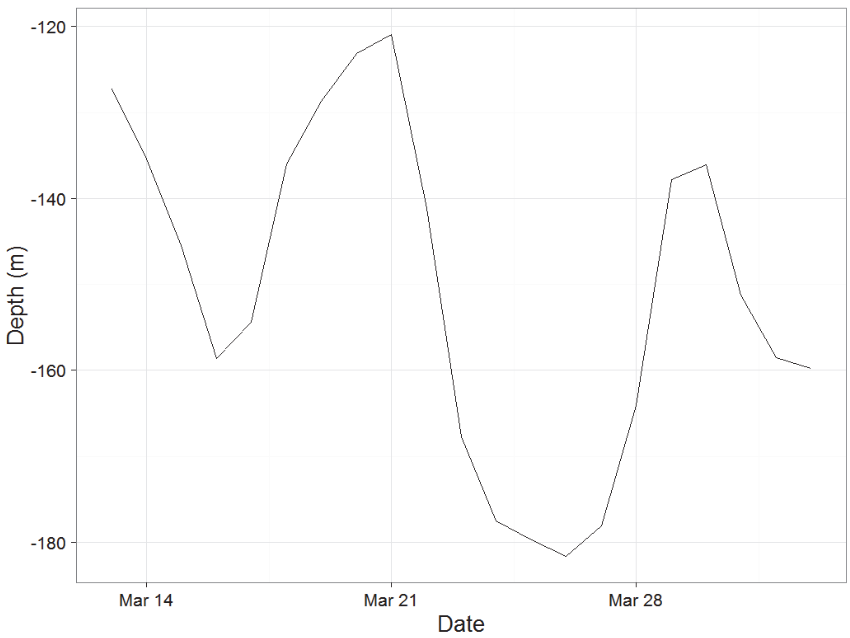

Figure A15. Depth data from skate 14; 21 days' deployment. Data is smoothed with 7 day moving average.

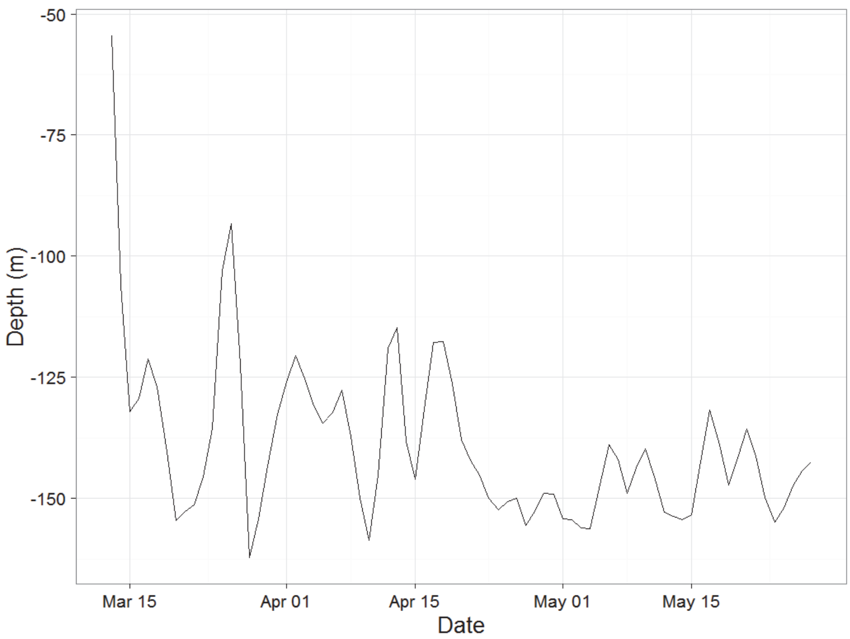

Figure A16. Depth data from skate 13; 77 days' deployment. Data is smoothed with 7 day moving average.

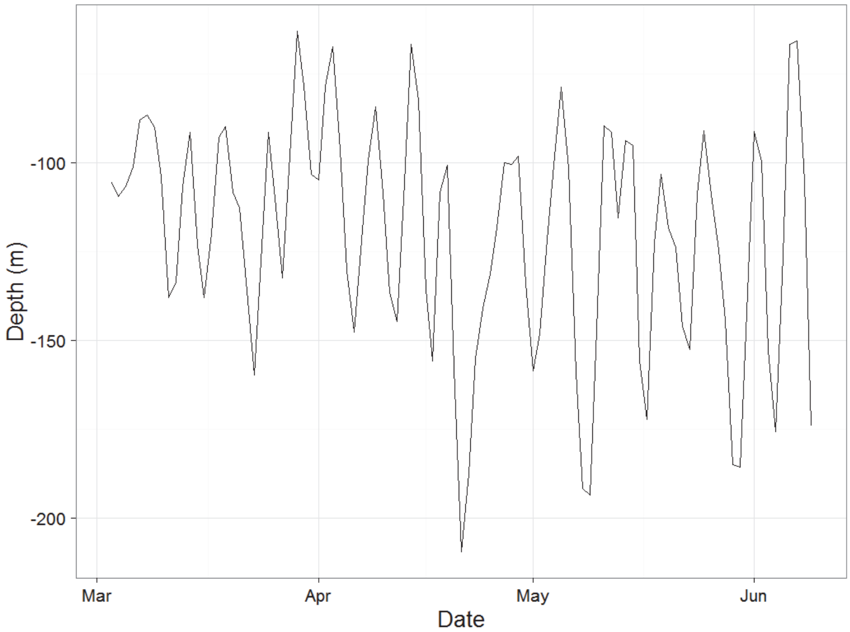

Figure A17. Depth data from skate 6; 99 days' deployment. Data is smoothed with 7 day moving average.

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