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Evidence of egg-laying grounds for critically endangered flapper skate (*Dipturus intermedius*) off Orkney, UK

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Abstract

Essential fish habitats (EFHs) are critical for fish life-history events, including spawning, breeding, feeding or growth. This study provides evidence of EFHs for the critically endangered flapper skate (*Dipturus intermedius*) in the waters around the Orkney Isles, Scotland, based on citizen-science observation data. The habitats of potential egg-laying sites were parametrised as >20 m depth, with boulders or exposed bedrock, in moderate current flow (0.3–2.8 knots) with low sedimentation. This information provides a significant contribution to the understanding of EFHs for flapper skate.

KEYWORDS
citizen science, common skate, egg-laying ground, egg nursery

The conservation status of large elasmobranchs globally remains precarious (Myers & Worm, 2003; Worm & Branch, 2012). The identification and protection of essential fish habitats (EFHs) (*i.e*., waters and substrata necessary for spawning, breeding, feeding or growth to maturity; *sensu* Martins *et al*., 2018) is a fundamental step towards threat mitigation. Recent working group reports have highlighted that information on EFHs is lacking for the flapper skate (*Dipturus intermedius*; Parnell, 1837) (Clarke *et al*., 2016; Garbett *et al*., 2020). This species is prone to fisheries capture across all life-history stages; as adults they swim throughout the water column and are caught in many types of fisheries gear, the juveniles are large and even the egg cases are prone to dredging (*e.g*., Dulvy *et al*., 2006; Neat *et al*., 2015; Figure 1, Supporting Information). The species is listed as critically endangered by the IUCN (Dulvy *et al*., 2006) and as prohibited under the common fisheries policy in EU waters since 2009 [Council Regulation (EU) no. 2020/123]. Despite the ban on landings, small numbers are still subject to by-catch or caught in ground fish monitoring studies (*e.g*., see Garbett *et al*., 2020). Regional measures also exist; for example, "common skate" complex is listed under Annex V of OSPAR regulations (Fowler, 2010), with a UK Biodiversity Action plan also in place (BAP, 2011).

Remaining localised refugia for flapper skate can be found from the Azores to the Faroe Islands (*e.g*., Dulvy *et al*., 2006; Fowler, 2010; Neat *et al*., 2015; Iglésias, pers. comm.). Nonetheless, to date, only two protected areas in Scotland offer spatial management specifically for flapper skate: the Loch Sunart to the Sound of Jura Marine Protected Area (MPA) (Thorburn *et al*., 2018) and an urgent temporary MPA announced for Sound of Skye (March 2021). Despite such important measures, the main threat to the species (*i.e*., fisheries) remains unchanged in many areas, and there is no quantitative evidence to suggest stock recovery (summarised in Garbett *et al*., 2020; Rindorf *et al*., 2020). In terms of skate conservation, the traits that make this (and other skate) species vulnerable to exploitation (residency, territoriality and suggested use of egg-laying grounds; *e.g*. Little, 1995; Neat

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et al., 2015; Wise, 2019) lend themselves to spatial management strategies. Similar to other large-bodied skates (*e.g.*, Hoff, 2016; Salinas-De-León *et al*., 2018; Treude *et al*., 2011), anecdotal evidence from scallop and recreational scuba divers suggests that flapper skate use egg-laying grounds. These sites, although highly vulnerable to disturbance, are spatially discrete, with identifiable physical characteristics allowing for focused management.

Protection of elasmobranch egg-laying grounds may enhance recruitment and support genetic diversity (Alaska Fisheries Science Center, 2020; Hoff, 2016). Such sites represent critical bio-potential and can be considered as EFHs (*sensu* Martins *et al*., 2018). Furthermore, given the relatively data-poor landscape for *D. intermedius* (recognised as a discrete species only in 2010; Iglésias *et al*., 2010), efforts to identify, understand and protect key areas are needed to ensure species recovery and focus conservation efforts (Garbett *et al*., 2020).

Current knowledge of flapper skate reproduction suggests a relatively low fecundity (<40 eggs per year; Du Buit, 1977), producing eggs which are large in size (*c*. 100–155 mm × *c*. 220–290 mm) (*e.g*., Dulvy *et al*., 2006; Shark Trust, 2009) (Figure 1b, Supporting Information). The embryonic development period is long, suggested to occur over 18–24 months (Wise, pers. comm., NatureScot, 2020), which increases the probability of disturbance, particularly as some egg-laying grounds appear to be associated with scallop and mussel fisheries (Co. Kerry, South West Ireland, Flannery, pers. comm.; Western Scotland, Wise, pers. comm.; this study).

The criteria used for defining skate egg case nurseries are consistent with many other elasmobranchs: (a) high densities of egg cases in contact with benthic/stationary materials, (b) adults using the area over multiple years for depositing eggs and (c) juveniles leave the area post-emergence (Hoff, 2016; Martins *et al*., 2018). If the juveniles remain at the site after emergence, the site also meets the definition of a juvenile nursery (Heupel *et al*., 2007; Hoff, 2016; Martins *et al*., 2018). Egg-laying grounds (where egg cases are noted on the benthos, without meeting the aforementioned criteria for an egg case nursery) for flapper skate have been inferred regionally, but to date none have been defined spatially. The identification of such sites is an important step as they would qualify as an EFH and should be the focus of conservation efforts for the species. Here the authors examined a range of citizen-science evidence (stranded egg case data, diver observations and towed camera surveys) to assess the presence of potential flapper skate egg case nursery off the Orkney Isles, Scotland (Figure 1).

Egg case stranding records were obtained from the Orkney Skate Trust *via* an *ad hoc* citizen science programme. Where possible, the

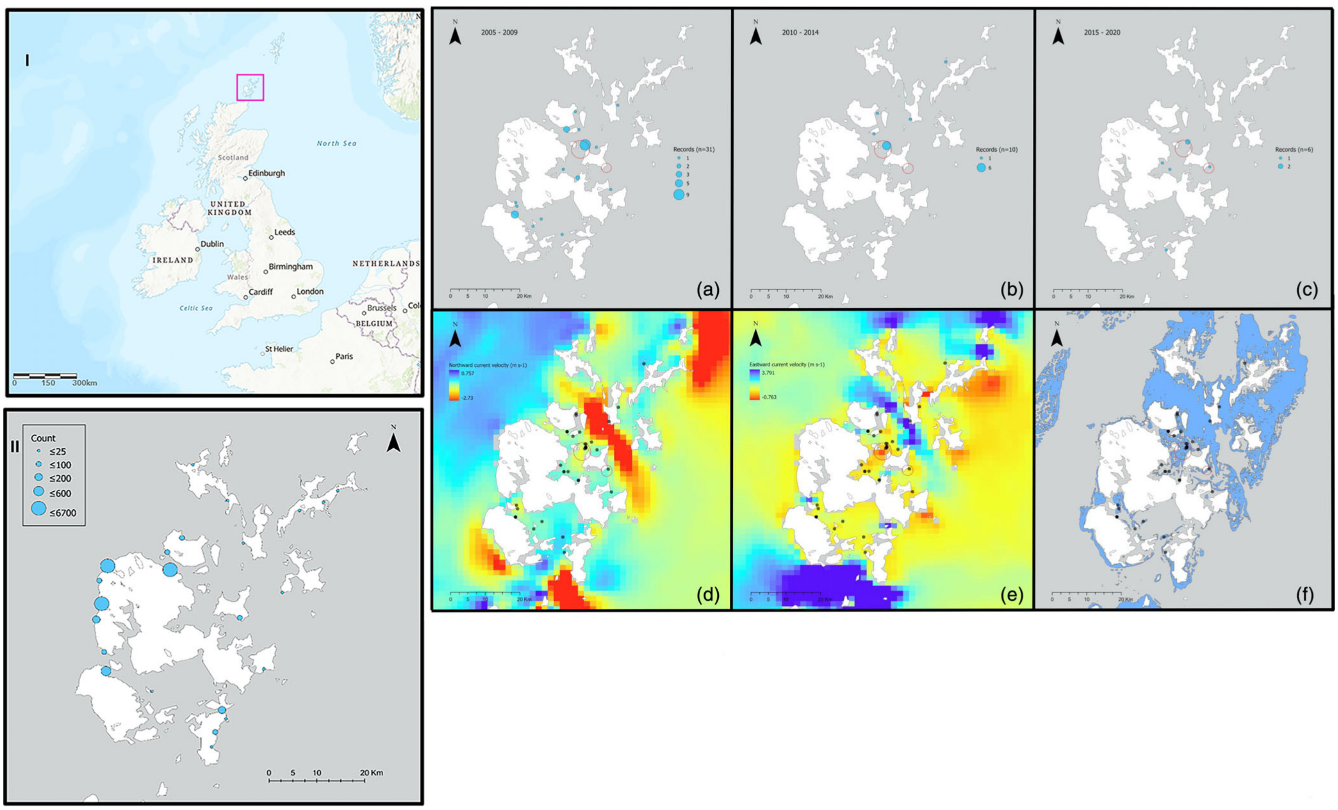

FIGURE 1 (I) Map of UK, with Orkney Islands highlighted in a pink box. (II) Map of flapper egg case records around the Orkney Islands. (III) Egg case data provided by the Orkney Skate Trust. Orkney dive sites with observed *in situ* flapper skate egg cases from 2005 to 2020; red open circles indicate sites of interest at the Foot of Shapinsay and Galt. (a–c) Maps showing *in situ* observations of egg cases, Orkney. Data points represent the number of records recorded at each location for the years (a) 2005–2009, (b) 2010–2014 and (c) 2015–2020. (d and e) *In situ* egg case observations overlaid on (d) northward and (e) current velocity data (m s^{-1}) obtained from E.U. Copernicus Marine Service Information (CMEMS, 2020). (f) *In situ* egg case observations in relation to hard-rock substrata indicated in blue (EMODnet, 2021)

state of egg cases was recorded (*e.g.*, empty, contains dead embryo). A random sub-sample of 48 egg cases were examined for traces of albumen (also described as embryonic jelly; Musa *et al*., 2018), which suggested recent hatching, and perhaps a seasonal hatching event. Records of egg case sightings that contained fewer than five egg cases per site were removed to prevent the over-interpretation of strandings that might have washed ashore as flotsam from further afield. Records lacking location data were removed from the data set, leaving 19,498 egg cases in total (372 egg case sighting records, each record containing 5–359 egg cases). All data were visualised using ArcGIS Pro GIS software (ArcGIS Pro, 2020) to highlight the total number of egg cases recorded per location (Figure 1).

Opportunistic dive data recording egg cases were collated by recreational and scallop divers through the Orkney Skate Trust. Dive locations were plotted where egg case presence was noted anecdotally over a 15 year period (Figure 1a–c) using ArcGIS Pro GIS. The number of egg cases recorded at each data point varied from 2 to 40 ($n = 47$).

Between April and May 2019, the Orkney Skate Trust carried out video transects ($n = 31$) using a drop-down "spy-ball" camera in depths of 6–62 m (Table 2, Supporting Information). For each transect, the camera was lowered to 2 m above the seabed, and the vessel was left to drift. Stations where egg cases were observed by towed video survey (<24 m) were further investigated by scuba. Three such dive transects (*c*. 100 m) were carried out. Subtidal egg case observations (mentioned earlier) were overlaid with current data and substrate data using ArcGIS Pro (Figure 1f). Current velocity data were obtained using the E.U. Copernicus Marine Service Information (CMEMS, 2020). Seabed habitat data were downloaded from EMODnet (EMODnet, 2021) as polygon-shaped files (Figure 1d,e).

Taken together, 19,948 flapper skate egg cases stranded around Orkney between 2004 and 2017 (Figure 1.II). These strandings were concentrated in three main sites around the north-west of Orkney (Figure 1). The majority of egg case strandings were recorded between January and April. The sub-sampled 48 egg cases contained traces of albumen, some with dead embryos ($n = 21$) (Figure 1, Supporting Information).

Diver surveys identified two sites where skate eggs were repeatedly recorded over a 15 year period: one at Galt and another at the Foot of Shapinsay ($n = 40$) (Figure 1a–c). Video surveys at Galt and Foot of Shapinsay recorded two and seven eggs, respectively. Sites with *in situ* egg cases recorded were characterised by boulder/rock substrates in high current flow (0.3–2.8 knots on spring tides, Admiralty Charts, 2021) (Figure 2, Supporting Information). These visual habitat classifications were validated using EMODnet and CMEMS data (Figure 1d–f).

Viewed more broadly, the use of egg-laying grounds is common across the large batoids, with discrete sites often used by multiple females over many years (Hoff, 2016). Increased efforts to identify, understand and protect such key sites are immediately needed to ensure long-term species survival (Garbett *et al*., 2020). Although the data presented here emerge largely from *ad hoc* citizen science, the large numbers of egg cases reported over 13 years are noteworthy.

Regarding the potential location of egg-laying nurseries around the Orkney Isles, the close proximity of egg deposition sites to stranding location is evidenced by the presence of albumen and dead embryos inside washed-up cases (Figure 1c, Supporting Information). Pre-hatching, the cases are negatively buoyant and, due to this, are unlikely to drift far from their deposition site. This suggests that egg cases getting washed up with embryos inside are likely to have originated in close proximity to the strand site. The higher numbers of stranded egg cases found in winter and the presence of albumen in the cases collected at this time may suggest a seasonal widespread hatching event. Nonetheless, these increased egg case numbers may also be due to winter storm action or varied levels of survey effort, so further investigation is recommended, using effort-based surveys to reduce the impact of sampling bias, to assess if there is a defined hatching season.

The diver observations highlighted the repeated use of an egg-laying ground offshore of the Galt, an area characterised by moderate current flow (0.3–2.8 knots on spring tides; Admiralty Charts, 2021) and boulder substrata. The repeated use of a site is characteristic of an egg nursery ground for skate (Hoff, 2016, *sensu* Martins *et al*., 2018). The large number of egg cases reported at the Foot of Shapinsay site would also be characteristic of an egg nursery ground. To confirm this classification, a SACFOR abundance survey (superabundant, abundant, common, frequent, occasional, rare) would require egg densities to be listed as "common" or above (Henry *et al*., 2016). Although these observations are tantalising, there is not yet enough evidence to confirm the sites' status as an egg case nursery for flapper skate, although the sites are clearly used more broadly as egg-laying grounds. Further quantitative investigations are recommended to confirm the densities of egg cases and to determine whether these sites qualify as EFHs.

The underwater observations allow one to tentatively parametrise some of the characteristics of flapper skate egg-laying grounds: boulder or rocky substrate, with significant current flow (up to 2.8 knots), fully marine conditions and >20 m water depth. The observations at Galt and Shapinsay highlight similarities in the habitat flapper skate lay their eggs in and the egg-laying habitats of other large skate species – deposition in rocky areas of high current flow, well-oxygenated water and low sedimentation to avoid suffocation (Luer & Gilbert, 1985; McEachran, 1970; Porcu *et al*., 2017; Rooper *et al*., 2019) (Table 1, Supporting Information). The use of boulder reefs (as noted here) as egg-laying habitat will help retain the egg cases *in situ*, providing shelter from winter storms, while allowing oxygenated water to flow (Hoff, 2016; Love *et al*., 2008). The high-energy boulder reef may offer some protection from egg predators such as whelks (*e.g.*, genus *Buccinum* or *Fusitriton*) which may have trouble sourcing the eggs where strong current flow affects chemoreceptor-sensing accuracy (*e.g.*, Cox & Koob, 1993).

Given that flapper skate fecundity is estimated at *c*. 40 eggs a year (Du Buit, 1977), the magnitude of strandings and in-water sightings data imply a substantial number of females in the region. As an example, the mean number of egg cases washed ashore in Orkney annually (between 2005 and 2017) was 1499, which would suggest a minimum of 38 gravid females in the vicinity. Nonetheless, the number of egg cases recorded by citizen scientists varies significantly between years as effort is not uniform spatially or temporally (annual recordings vary by *c.* 8290 egg cases over the 12 year period), and repeat counts may occur within shorter time frames. Further effort-based surveys of egg cases are highly recommended to enable temporal comparisons; for example, the mean number of egg cases washed ashore annually between 2015 and 2016 was substantially higher ($n = 9911$), which would be equating to a theoretical 123 gravid females in the area. Further survey data could provide seasonal and annual analysis of egg case abundance patterns and an assessment of how the area is being used by gravid females. Overall, the high number of egg cases implies that high numbers of juvenile skate are recruited from the area.

Determining the provenance of the washed-up egg case aggregations on the north-west coast of Orkney requires further investigation, and the relationship between these egg cases and the subtidal eggs is not yet clear. Nonetheless, an examination of the tidal current directions (reaching 2.8 knots; Admiralty Charts, 2021), flowing out of the area encircled by Orkney Mainland, Rousay and Shapinsay, may provide insights into the provenance of some egg cases (see Figure 2, tidal charts, Supporting Information; Orkney Islands Council Harbour Authority, 2021). This area is sheltered from the extremes of stormy weather by the surrounding islands but retains strong current flow, with a deeper area towards the Foot of Shapinsay. This site has been noted to contain skate egg cases and is characterised by a deep-water, boulder-strewn refuge, which is typical of many large skate egg-laying grounds. Current patterns suggest that empty egg cases from this region would be washed in an east-southeast direction, through "The String" into Shapinsay Sound and out into the North Sea (see Figure 2, Supporting Information; Orkney Islands Council Harbour Authority, 2021). Alternatively, the egg cases could be swept west-northwest between Rousay and Orkney Mainland, before sweeping south-west along the west coast of Orkney where stranding is highly likely (Orkney Islands Council Harbour Authority, 2021). This west-northwest route may explain the extremely large numbers of egg cases found along the Orkney north-west shoreline.

To conclude, the information presented here was obtained from an enormous effort at community level. By compiling such data sets from citizen-science schemes, local surveys and national recording schemes, this study has been able to explore the ecology of a critically endangered species and highlight a site that may prove vital for flapper skate conservation.

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CONFLICTS OF INTEREST

The authors declare that they are not aware of any competing interests.

AUTHOR CONTRIBUTIONS

N.D.P., A.G., S.L.L., O.D., L.E.E. and J.D.R.H. were involved in writing and editing the manuscript. D.W. and P.V. assisted with conceptualisation and review. J.T. helped with review. P.C.C. was involved in conceptualisation, writing and editing.

ETHICAL STATEMENT

This study did not involve animal experimentation or harm and required no permits.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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