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BRIEF COMMUNICATION

First observation of a skate egg case nursery in the Ross Sea

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Abstract

Areas of importance to Southern Ocean skates are poorly defined. Here, we identify a deepwater skate egg case nursery in a discrete location at ~460 m depth off Cape Adare in the Southern Ocean. This is the first confirmed observation of a skate nursery area in the Ross Sea and only the second observation for the Southern Ocean. The morphology and size of the egg cases were consistent with the genus *Bathyraja* and most likely belong to the *Bathyraja* sp. (cf. *eatonii*). The nursery occurs within the "no take" General Protection Zone of the Ross Sea region marine protected area, where commercial fishing is prohibited.

KEYWORDS
Antarctica, *Bathyraja* sp. (cf. *eatonii*), batoid, habitat use, life history, marine protected area, Southern Ocean

The delineation of sites of importance to species is essential for area-based conservation initiatives, which provide species with refuge from human activities (Hyde et al., 2022). For elasmobranchs (sharks and rays), the designation of spatial refuge from the impacts of fishing is becoming increasingly important as the global extinction risk of these species increases (Dulvy et al., 2021). The current understanding of habitat use by elasmobranchs is poor, and key habitats of importance are unknown for most species (Simpfendorfer & Heupel, 2004). This lack of information is particularly pronounced for deepwater species and in remote areas like the Southern Ocean. Deepwater elasmobranchs (species found at depths greater than 200 m) are among the most data-poor species because of their deep depth distributions, cryptic nature, and the high costs of deep-ocean biological surveying (Finucci et al., 2022). Deepwater elasmobranchs are also some of the most susceptible of the cartilaginous fishes to population decline from overexploitation because of their larger body sizes and slow life histories (Dulvy & Reynolds, 2002; Rigby & Simpfendorfer, 2015).

Skates are an important by-catch of bottom longline fisheries targeting toothfish (*Dissostichus* spp.) in the Southern Ocean (Faure et al., 2023; Finucci et al., 2023; Finucci & Moore, 2022; Moore & Parker, 2021). Two genera of skates (*Amblyraja* and *Bathyraja*) are known to occur in the Southern Ocean, comprising at least nine described species: Antarctic starry skate *Amblyraja georgiana* (Norman 1938), Arctic skate *Amblyraja hyperborea* (Collett 1879), whiteleg skate *Amblyraja taaf* (Merisner 1987), Antarctic dark-mouth Skate *Bathyraja arctowskii* (Dollo 1904), Eaton's skate *Bathyraja eatonii* (Günther 1876), Kerguelen sandpaper skate *Bathyraja irrasa* (Hureau & Ozouf-Costaz 1980), McCain's skate *Bathyraja maccaini* (Springer 1971), dark-belly skate *Bathyraja meridionalis* (Stehmann 1987), and Murray's skate *Bathyraja murrayi* (Günther 1880). Despite their presence as fisheries by-catch, there is generally limited information about the life history and habitat use of Southern Ocean skates. There is at least one undescribed species, *Bathyraja* sp. (cf. *eatonii*), a large skate suspected to occur within the Ross Sea region (A. Stewart, Te Papa, pers. comm.).

Skates are oviparous, with females laying large eggs where embryos develop over prolonged incubations lasting from months to years (Hoff, 2009). Eggs are often deposited in confined areas and at

high densities (Hoff, 2010; Hunt et al., 2011). Egg case nursery habitats are considered "essential fish habitats," necessary for the long-term survival of species (Heithaus, 2007). Several criteria have been defined to identify egg case nurseries (Martins et al., 2018), including (1) high densities of egg cases in contact with benthic or stationary materials; (2) adults using an area or habitat to lay egg cases repeatedly over multiple years; and (3) newborn or YOY individuals leaving the area promptly after hatching.

At the time of writing, there is only one egg case nursery habitat reported from the Southern Ocean, imaged during a photographic survey along the seafloor: a discrete location along the continental shelf and slope west of Anvers Island in the western Antarctic Peninsula between a narrow depth band of 394–443 m (63·53°S; 66·05°W to 64·30°S; 67·43°W) (Amsler et al., 2015). This egg case nursery was suspected to belong to *B. maccaini*, *Bathyraja* sp. (cf. *eatonii*), or *Bathyraja* sp. (dwarf) based on the known geographic and bathymetric distribution of adults. Other sub-Antarctic egg case nursery areas have been reported further north, including seamount nurseries for *A. hyperborea* and Richardson's skate *Bathyraja richardsoni* (Garrick, 1961) south of Tasmania, Australia, and multispecies nursery areas on Burdwood Bank, east of Isla de los Estados, Argentina (Florencia et al., 2022; Maguire et al., 2023).

In January and February 2019, a photographic survey of the benthic community along the continental shelf/slope was conducted aboard RV *Tangaroa* in the Ross Sea as part of a wider programme established for monitoring the Ross Sea region Marine Protected Area (MPA), declared in 2017 (TAN1901, Dunn et al., 2017; O'Driscoll et al., 2019). The National Institute of Water and Atmospheric Research (NIWA)'s Deep Towed Imaging System (DTIS) collected towed video and still imagery at 33 sites: 4 sites at the shelf break off Cape Adare; 27 sites in the six demersal slope strata; 1 site on the continental shelf; and 1 site on Scott C seamount.

DTIS is a battery-powered towed camera frame deployed on a power-and-communication cable, which records continuous high-definition digital video (1080p, Sony HDR PJ series) and simultaneously takes high-definition still images (24 megapixel Nikon D3400) at 15-s intervals. The video camera faces forward at approximately 40° from vertical, and the still camera faces directly downward (0° from vertical). DTIS transects were at a target altitude above the seabed of 2.5–3.5 m, with the ship in dynamic positioning mode to control speed and direction for optimal image quality and seabed position and depth of DTIS tracked in real time using the SIMRAD HiPAP system. A Seabird Microcat CTD was attached to the DTIS frame during all deployments to record salinity, temperature, and depth data. The seabed position of DTIS was plotted in real time using Ocean Floor Observation Protocol (OFOP) software (https://www.emmatechnologies.com).

Biological sampling of the seabed focused on the same strata and the same set of randomly selected survey sites. At each site, a seabed area of ~4 × 4 nautical miles (NM) was mapped by two or three (depending on depth) multibeam echosounder lines, within which a DTIS transect of 0.5–0.6 NM (1 h at a target speed of 0.6 kt) was run. This created 33 h 38 min of seabed video and 8116 images. The mean transect distance was 986 m (maximum 1607 m; minimum 574 m; S.D. 196 m), representing total seabed imaged areas of 113,914 m^2 (0.11 km^2) and 48,696 m^2 (0.05 km^2) from video and still imagery, respectively.

All still imagery and video analysis was completed in BIIGLE 2.0 (Langenkämper et al., 2017). Egg cases were annotated at first appearance on the video and were also identified on still images. Egg cases were classified into one of six categories based on color and condition, following classifications by previous studies (Henry et al., 2016; Maguire et al., 2023; Salinas-de-León et al., 2018) (Table 1). These categories give an indication of the age and development of egg cases, with categories (1) and (2) indicating "recently laid" egg cases and categories (3) to (5) signifying "aged" egg cases that have been subject to environmental conditions over an extended period of time on the seafloor. Egg case length (ECL, cm) was measured for unobstructed "recently laid" eggs from still images to assist with species identification (White et al., 2022). Benthic fauna were counted and identified to coarse taxonomic levels on the still images. ANOVA was used to examine species and/or habitat association with the skate egg case nursery (Veech, 2021). Additional sources indicating where skate egg case nurseries may occur in the Ross Sea region were collated, and their localities were mapped. These sources included gravid skates examined in the laboratory at NIWA and observer records of gravid skates examined at sea ($n = 16$; B. Finucci, unpublished data), and skate egg cases held at the Museum of New Zealand Te Papa Tongarewa ($n = 57$).

Skate egg cases were observed along one transect on the shelf break at depths between 460 and 474 m (mean = 461 m) off Cape Adare (71.43°S, 171.97°W, TAN1901_064) (Figure 1a). The transect began on the summit of a low knoll and traveled 1.06 km down along the slope over the duration of an hour, covering an imaged area of 3.71 km^2 with video (O'Driscoll et al., 2019). The mean bottom temperature was −1.78°C (−1.75 to −1.80°C), and the mean salinity was 34.73 PSU (34.72–34.78 PSU). A total of 337 skate egg cases were counted on the video. Most egg cases lay flat on the seafloor and did not appear to be anchored to the seafloor. There was no obvious pattern of orientation (Figure 1b). Egg cases were noted in 59 of the 243 paired still images in the single transect ($n = 146$ egg cases), and 28 images had multiple egg cases (maximum $n = 14$). Most egg cases were found at 394–443 m depth, with a few egg cases imaged at transects to 1100 m depth.

Most egg cases on the video were "recently laid" and golden (29.7%) or dark brown/black (22.8%) in color, whereas, in the still images, most egg cases were classified as "aged," fouled (26.7%), sedimented (19.9%), or degraded (19.2%) (Table 1). The varying state of the egg cases suggests that this area may be used year-round and may represent multiple generations of developing embryos (Amsler et al., 2015). Most egg cases (87.2%, $n = 294$) were observed within the first 20 min of the video, showing high site selection by females, and there was no pattern where egg cases were deposited based on their condition. Egg case density where egg cases were most abundant (first 20 min of video) was estimated at 0.26 m^{-2}.

TABLE 1 Skate egg cases on video and still images by categories and descriptions (as described in Maguire et al., 2023).

			Video		Still images	
Age/development	**Category**	**Egg case description**	***n***	**% Total**	***n***	**% Total**
Recently laid	Golden	Part or whole egg case has a golden color, appears intact and without sediment coat or fouling, and is in a good condition	100	29.7	28	19.2
	Dark brown, black	The egg case has a uniform dark brown or black color (differentiated from egg cases in shadows) without sediment coat or fouling	77	22.8	17	11.6
Aged	Sedimented	The egg case has a uniform, light shade of brown-gray color due to being lightly coated with debris/sediment but not fouled with invertebrate or microbial growth	89	26.4	29	19.9
	Fouled	The egg case appears fouled with invertebrate (e.g., sponge, coral, or crustacean) or microbial growth; the egg case can be relatively intact (may be broken open but not fragmented)	17	5.0	39	26.7
	Degraded	The egg case is fouled and damaged, usually in separated fragments	51	15.1	28	19.2
N/A	Not clearly visible	The egg case is either too far away, shadowed, or at an angle where identification is not possible	3	<1	5	3.4
	Total		337		146	

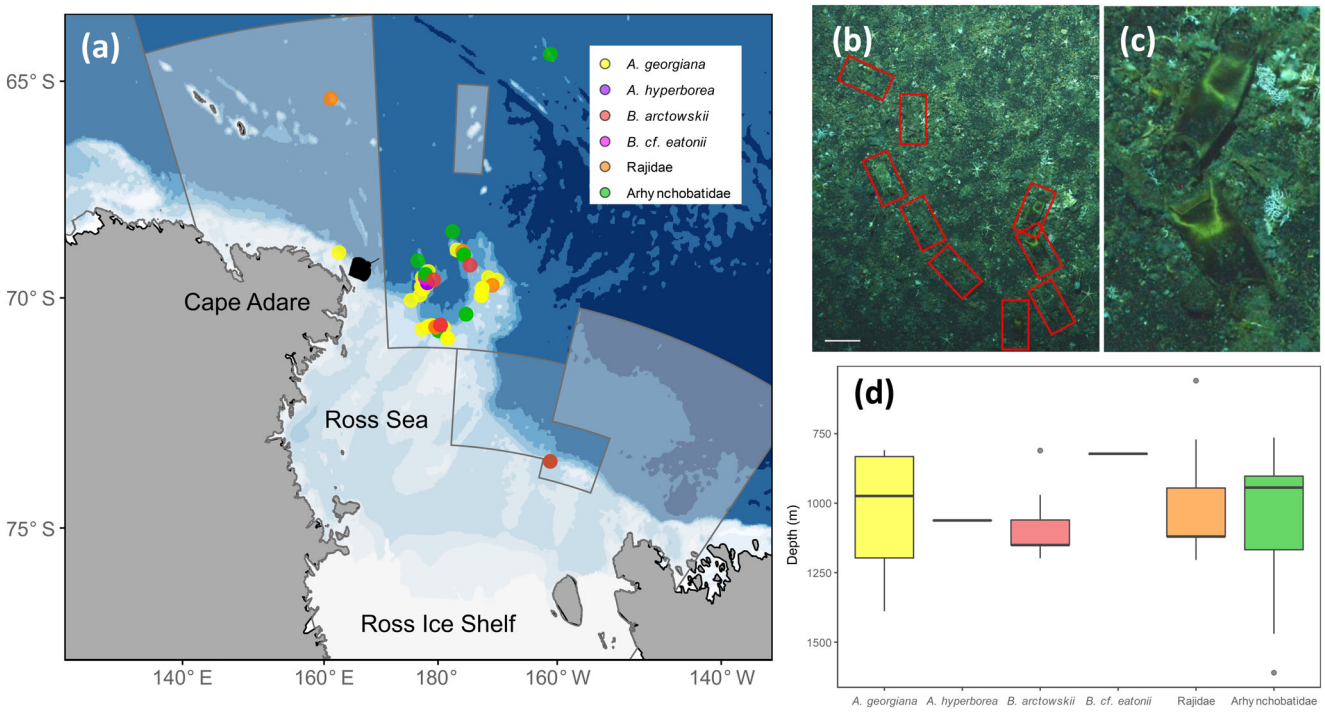

FIGURE 1 (a) Location of the skate egg case nursery (black skate icon) in the Ross Sea and location of other skate egg cases by species or skate family recorded in the Ross Sea region. The General Protection Zone of the Ross Sea region marine protected area is shaded in gray. (b) Still image of the skate egg case nursery with skate egg cases identified in the red boxes. (c) Still image of the skate egg cases in greater detail. (d) Depth distribution of skate egg cases recorded in the Ross Sea by species or family.

The morphology of egg cases was consistent with the genus *Bathyraja* (Australian National Fish Collection, unpublished data). The average ECL (excluding the horns) was 10.7 cm (8.4–12.5 cm). Based on the length of the egg cases, as well as species known to occur in the Ross Sea region, it is most likely that the egg cases belong to the species *Bathyraja* sp. (cf. *eatonii*). There was no indication to suggest that more than one species of skate was using this area as a nursery. Egg-laying sites are generally used by a single species for egg deposition, but multiple species may use the habitat (Hoff, 2010). Additional records suggest that there may be some overlap in spatial

habitat use between species of the Rajidae and Arhynchobatidae families in some areas (Figure 1a). It is not clear if there is any depth separation of habitat use (Figure 1c). No juvenile or adult skates were observed during the survey for visual confirmation of species identification. However, this was not surprising given that skates can use discrete areas for nurseries, one for egg deposition and another for newly emergent juveniles (Hoff, 2016).

The densest patch of skate egg cases was found on a flat, coarse black sand substrate that was often covered with patches of shell, bryozoan, and barnacle plate hash. A small number of egg cases were also observed lodged near rounded and angular boulders; these egg cases were in an advanced stage and may have been displaced from their initial location. Invertebrate fauna included erect and encrusting sponges, ascidians, bryozoans, ophiuroids, asteroids, *Flabellum* sp. solitary corals, some gorgonians (mainly *Thouarella* sp.), octopus, *Psolus* sp. holothuroids, heart and cidaroid urchins, motile crinoids, *Umbellula* sp. sea pens, asteroids, gastropods, serolid isopods, and pycnogonids. Some skate egg cases were biofouled with ascidians, bryozoans, and encrusting sponges. Three species of teleosts were observed among the skate egg case nursery: saddleback plunderfish *Pogonophryne scotti* Regan, 1914; *Bathydraco* cf. *macrolepis* Boulenger, 1907; and striped-eye notothen *Lepidonotothen squamifrons* (Günther, 1880). Skate egg case presence and abundance were significantly associated with the presence of ophiuroids (Ophiuroidea) and bryozoans (Bryozoa) ($p < 0.05$). Egg case presence was also significantly associated with ascidians (Ascidiacea) ($p < 0.05$).

The size of this skate nursery area was relatively small compared to other known skate nursery areas (e.g., reported density is 800,000 egg cases km^{-2} in a Bering Sea canyon nursery; Hoff, 2010) but was comparable in size (~26,000 egg cases km^{-2}) with the nursery area observed off Anvers Island (Amsler et al., 2015). The western Antarctic Peninsula reported 185 skate egg cases, and an estimated density of 20,000 egg cases km^{-2} across the imaged area (Amsler et al., 2015). It was hypothesized that the imaged area may be the periphery of the main nursery area, beyond the surveyed area (of ~135,000 m^2) (Amsler et al., 2015). Here, 113,914 m^2 of seafloor area was imaged, and only one other transect was observed to have skate egg cases ($n = 2$, site TAN1901_072). It is possible that higher densities of egg cases may be observed elsewhere or at deeper depths. Egg case nurseries for *A. hyperborea* have been reported from bathyal depths of up to 1900 m (Maguire et al., 2023). However, other video surveys conducted in the Ross Sea region in 2008, 2018, and 2021 have yet to observe skate egg cases. Additional observations of skate egg cases or gravid female *A. georgiana* collected from fisheries have largely been reported along Mawson Bank and Isin Bank at depths from 809 to 1389 m (median depth = 974 m) (Figure 1d). The shallowest and deepest Ross Sea skate egg case records are 559 and 1610 m for unidentified Rajidae and Arhynchobatidae species, respectively.

Skate egg case nurseries have previously been reported from narrow depth ranges on the continental shelf and slope and in waters with constant bottom temperatures (Amsler et al., 2015; Hoff, 2008; Hoff, 2010). Environmental conditions on the slope off Cape Adare are influenced by bottom-water currents, with regular seasonal influxes of high salinity shelf water from the nearby Drygalski Trough, resulting in exchanges of increased salinity and density (Bowen et al., 2021, 2023). Potential bottom water temperatures at Cape Adare are relatively stable, varying between −1°C and 1°C (Bowen et al., 2021). Oviparous elasmobranch embryonic development is directly related to temperature, with warmer temperatures reducing hatching times (Hoff, 2008; Wheeler et al., 2020). Hoff (2008) estimated an embryonic development period of 3.5 years for the Alaska skate *f* (Bean, 1881) in the Bering Sea where the mean bottom temperature was 4.4°C. A prolonged embryonic development period would also be expected for the egg case nursery here in the Ross Sea given the cold bottom temperature.

Since 2014, salinity off Cape Adare (and the wider Ross Sea region) has increased and is linked to sea ice production in the region (Bowen et al., 2023). Salinity has been shown to have a strong influence on elasmobranch physiology; most sharks and rays occupy a narrow salinity range, and, thus, changes in water salinity can influence distribution and movement patterns (Schlaff et al., 2014). It is unclear if these recent regional salinity increases will continue or are simply shorter-term variations within the longer-term trend in freshening observed since the 1950s (Jacobs et al., 2022). However, given the presumed prolonged embryonic development period required before hatching, the newly discovered skate egg case nursery presented in this paper may be exposed to, and at risk from, changing ocean conditions in the short (1–5 years) and medium terms (5–30 years), and future monitoring of the area is important.

The Ross Sea region MPA was established in 2017 and is the world's largest MPA, measuring 1.55 million km^2 (Dunn et al., 2017; MFAT, 2023). The MPA is divided into three zones, the largest part of which (>70%, 1.12 million km^2) is the General Protection Zone. This is a fully protected area where no commercial fishing is permitted. The MPA was established to protect important habitats and foraging areas for marine life, including iconic marine megafauna such as Weddell seal *Leptonychotes weddellii* Gill, 1872; killer whale *Orcinus orca* (L. 1758); emperor penguin *Aptenodytes forsteri* Gray, 1844; Adélie penguin *Pygoscelis adeliae* (Hombron & Jacquinot, 1841); and Antarctic toothfish *Dissostichus mawsoni* Norman, 1937. This paper shows that the MPA also provides protection for at least some of the essential habitats of Ross Sea skates.

AUTHOR CONTRIBUTIONS

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