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Description of a collaborative sperm whale birth and shifts in coda vocal styles during key events

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Wild cetacean birth observations are extremely rare, with observations having been recorded in less than 10% of cetacean species. Here, we describe a detailed accounting of a sperm whale (*Physeter macrocephalus*) birth off the coast of Dominica within a well-documented social unit and consisted of sperm whales collaboratively lifting the newborn out of the water. We recorded data via multiple concurrent methods: underwater audio, aerial drone video, shipboard photography in addition to behavioral observations spanning before, during and after the whale birth. All 11 members from sperm whale "Unit A" were present and participated in the birth, which lasted 34 min from the time the flukes emerged until the completion of delivery. The sperm whale unit made extensive vocalizations, with statistically significant shifts in coda vocal style corresponding to key events, such as the beginning of the birth and interactions with short-finned pilot whales (Globicephala macrorhynchus) shortly after the birth event. An evolutionary analysis of wild cetacean births suggests that newborns being lifted out of the water dates to before the most recent common ancestor of toothed and baleen whales, > 36 million years ago, and that cooperative lifting of the newborn is noted, thus far, only in members of Odontoceti (toothed whales). This study provides the most in-depth observations of a wild cetacean birth.

Keywords Sperm whale birth, Vocal style, Physeter macrocephalus, Cetacean biology, Birth orientation

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In 1839, Thomas Beale, a British surgeon, noted in *The Natural History of the Sperm Whale*, that female sperm whales "are very remarkable for attachment to their young, which they may be frequently seen urging and assisting to escape danger with the most unceasing care and fondness"[1]. Over the past several decades, field research on sperm whales (*Physter macrocephalus*) has supported this observation and suggested that the collective care for calves is a driving force behind the evolution of group living in this species[2–7]. However, observations of how sperm whales enter the world, in their natural environment, have been extremely scarce. For example, in the last 60 years, there is only one previous scientific observation of a sperm whale birth[8] and four other published accounts with observations just following sperm whale births[9–12] were recorded during whaling activities (**Table 1**). This makes this study the most comprehensive observations of a sperm whale birth published; and the most detailed observation across any natural wild cetacean birth.

An understanding of labor, birth, postnatal, and neonatal behavior is lacking for many cetacean species[13], as these events are observed and documented infrequently. Of the described 93 species of cetaceans[14] only nine species have reported birth observations collected in the wild[8,10–12],. And reports of birth events of pelagic, deep-diving cetacean species, such as sperm whales, are exceptionally rare (**Table 1**). Sperm whales are born after approximately a 14–16 month gestation period[15], which is among the most lengthy in the animal kingdom. Calves are born at approximately 4 m long[15] and are dependent on breast milk for at least two years[5,15]. At birth, calves appear to be negatively buoyant[16], but become proficient swimmers within a few hours[8], and as they age, they become the social hub of the social unit's interactions through babysitting as well as allonursing in some sperm whale units[3–36].

In this study, we report detailed underwater audio, aerial drone video, shipboard photography, and behavioral observations of a sperm whale birth off the coast of Dominica in the Eastern Caribbean. This extensive documentation presents a unique opportunity to glean insights into a critical behavioral event for a marine mammal. This study builds on previous scientific observations, including a comprehensive review of reports of whale births over the past century, and notes key features and similarities that occur with cetaceans at birth. It also describes cooperative social behavior, such as coordinated lifting the newborn out of the water, that likely plays an essential role in enabling sperm whales to successfully reproduce in deep water. This birth event attracted the attention of two other marine mammal species, short-finned pilot whales (*Globicephala macrorhynchus*) and Fraser's dolphins (*Lagenodelphis hosei*). These interactions are described and put into context of all previously documented cetacean birth events where lifting behavior and other cetaceans were present.

Results

On July 8, 2023, the Project CETI (Cetacean Translation Initiative) team encountered 11 sperm whales (8 adults and 3 calves) from the well-studied Unit A off the coast of Dominica (start of encounter at 09:50 local Dominica time; location N 15°22.212" W 61°29.721") (**Fig. 1**). Recordings include a total of 5 h and 22 min, and a detailed behavior and event timeline is provided in **Table S1**. Key events are summarized below. 11:45:45 local Dominica time is noted as the birth time and is listed as T = 0 or 11:45:45 [00:00:00] for ease of denoting the timescale of events.

Background/family tree of sperm Whale unit A All individuals within Unit A were identified as present over the course of the day (Fig. 2) either through drone video or DSLR photo-identification, including a 15 year old sub-adult male, *Allan* (2008, whale #6088), the parturient's half-brother, who had already begun to separate from his natal unit about six years before this birth event. Unit A was initially documented photographically off Dominica in 1996[37]and is one of the most sighted units off Dominica. They have been identified in 873 unique clusters (a set of whales observed together coordinating their behavior, within three body lengths of each other on 126 days in 16 different years since the onset of continuous research in 2005[38]. The unit is made up of two matrilines

Publication	Date/Location	Lifting newborn observed	Other cetaceans present	Sharks present
Weilgart & Whitehead 1986	10/21/1983 off Trincomalee, Sri Lanka at 9°01.8'N, 81°29.7'E	Not mentioned. six sperm whales present. 'energetic behavior' including squeezing the calf between adults.	Bottlenose dolphins and false killer whales, sighted within 150 m of the whales and the boat.	No. But, noting Gambell 1968 and Gambell et al. 1973: "We saw no sharks at the time of birth, account for the differences observed in the number of whales attending."
Correia-Fagundes & Romano 2013	08/02/2013 3.9 miles SE of Machio, Madeira 32° 38' 41" N 16° 45' 12" W	Not mentioned.	"No other cetaceans sighted in the vicinity"	Not mentioned.
Gambel, Lockyer, Ross 1973 **Whaling Related.**	2/9/1973 ~ 48 nm off South Africa 33°49'S, 28°02'E	18 sperm whales present. Adults did not assist, but whaling activity occurred.	False killer whales around newborn	Shark seen attacking sperm whale fetal membranes lying at the surface
Gambell, 1968 **Whaling Related.**	5/3/1966 Off Durban, South Africa	"surrounded and supported by other cows"	"Surrounded by a vast school of dolphins who kept a continuous circle around the sperm [whale]."	Many sharks reported present
Pervushin A.S. 1966 **Whaling Related.**	3/26/1964 37°01' South, 71°73' East in the open Southern Indian Ocean	Two adults were constantly diving under to support the newborn. "two groups of sperm whales were spotted from the captain's bridge. Each group had roughly 20 individuals in it."	Not mentioned	No. Notes: "In the tropical or subtropical waters the blood spilled during the birth would attract a lot of sharks."

Table 1. Previous published records of sperm Whale births.

Fig. 1. Pre-birth gathering of the sperm whales of Unit A.

which likely share a distant common ancestor[39]. The first of the two female lines has two elder females, *Atwood* (whale #5585) and *Lady Oracle* (whale #5712). Consistent sperm whale research off Dominica began in 2005, and since that time, *Lady Oracle* birthed *Rounder* (pre-2005, at least 19 years old at this birth event, whale #5714), followed by *Allan* (2008, whale #6088) and *Aurora* (2016, whale #6302), meaning *Allan* and *Aurora* are in the *Lady Oracle* matriline. *Lady Oracle* became a grandmother when *Rounder* birthed *Accra* (2017, whale #6301).

The second matriline consists of *Fruit Salad* as the eldest female. *Fruit Salad* birthed *Soursop* (pre-2005, whale#5719), and *Soursop* subsequently then had *Ariel* (2018, whale #57191). In addition, there was a young-of-year (born within the past year) within the unit, an observation made as part of the documentation of this birth, but the identity of its mother is uncertain. Other adult females from Unit A have died since the start of these ongoing observations. *Oryx* disappeared in 2010 (whale #5723), and while her older offspring *Snow* (pre-2005, whale #6196) has survived to adulthood, her younger calf *Crake* (2009, whale #57232) did not survive[40].

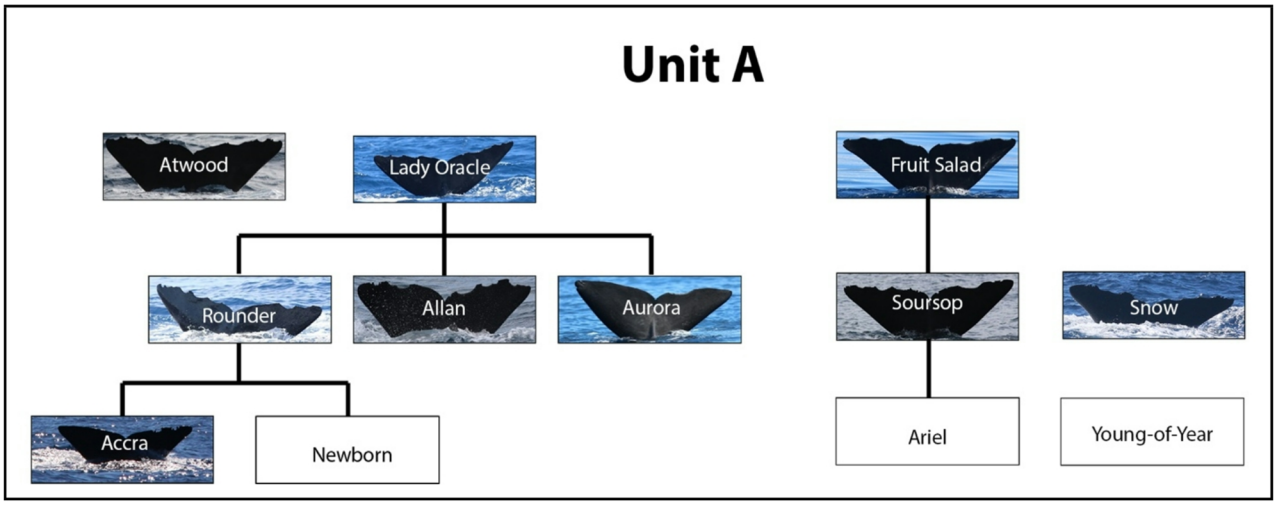


Fig. 2. The pedigree of living members of Unit A based on both social and genetic analyses (see[38,39]. All individuals are female, except *Allan*. The sexes of *Ariel*, the young-of-year, and the newborn are unknown.

Pre-birth

We first encountered the 11 sperm whales of Unit A in a tightly grouped formation and making several slow shallow dives (Fig. 1; **Video S1**), while also vocalizing codas before the onset of our acoustic recordings (heard from hydrophones used to initially locate the whales). At 10:48 [−00:57] the unit began moving in a southerly direction and became increasingly more active. Our first acoustic recording began at 10:53 [−00:52].

Birth

At 11:12 [−00:33] the birth began when the tips of the newborn's flukes were observed emerging from the mother (identified as *Rounder*; see Fig. 3). Other adult females were consistently oriented towards the birth and were observed repeatedly diving under *Rounder's* dorsal fin, often belly up, with their head towards her genital slit. At 11:42 to 11:45 [−00:03:45 to −00:00:45], blood and feces were observed in several brownish-red plumes. At 11:45 [−00:00:45], *Rounder* rolled her body and the emerging newborn could be observed with its head still inside its mother (Fig. 4). Following this roll, a large amount of blood appeared. At 11:45:45 [00:00:00] - the birth was complete.

Post-birth

11:47 [00:01:15] - The newborn sperm whale surfaced for the first time, emerging right beside the mother's head. As such, the time from the first observation of the calf's flukes to the completion of the birth lasted ~ 34 min. Immediately following the birth, the activity level of the unit rapidly changed, the newborn's unit members including the younger juvenile animals became highly active, with all adults squeezing the newborn's body between theirs, touching it with their heads, and all animals directing their noses towards the newborn; often pushing it around, under the water, and onto and across their bodies above the surface. After some active rolling with the other members of Unit A, the newborn was lifted onto the heads of the adults and the umbilical cord was visible, along with clear fetal folds (Fig. 5b) and the tail flukes were initially folded (Fig. 5).

The newborn was often at the front of the unit, sometimes being pushed laterally by the heads of members of Unit A, enough to change the newborn's orientation. During this time, nearly all the animals were in physical contact as they moved. During this period the whales moved towards the CETI-1 research vessel (40' Catamaran), which had its sails down and engines off, to within less than 1 m, and at one point a whale grazed the stationary sailboat.

The unit remained in a tight cluster, very active and rolling, with the newborn at or near the surface, or on the bodies of the adults, above the surface, for about 20 min as the cluster continued eastward towards the island. This behavior continued past 12:00 [00:14:15] when the first of the short-finned pilot whales, which had been sighted in the area prior to encountering the sperm whales in the morning (first sighted around 09:18 [−02:27:45] and estimated to be between 50 and 150 individuals in several groups), was observed within 10 m of the sperm whale cluster which included the newborn. At this point, the sperm whale unit slowed down while remaining in tight proximity and coordinated in their heading, but there was less rolling and activity.

The newborn was often on top of, or squeezed between, multiple adult females. There were several interactions between short-finned pilot whales and sperm whales over the course of the subsequent two hours, including at least one occasion of very close contact (< 1 m) between the mother and several close approaches (< 3 m) to the mother and newborn; as well as, a larger number of pilot whales around the cluster (including the newborn) and possibly causing the sperm whales to abruptly change direction, often when multiple pilot whales were positioned directly in front of the sperm whale cluster. At least one adult female sperm whale was always positioned between the newborn and the pilot whales, including from below. In a few cases, there was a clear response, when pilot whales got extremely close to the sperm whales' heads or the newborn, where the adults

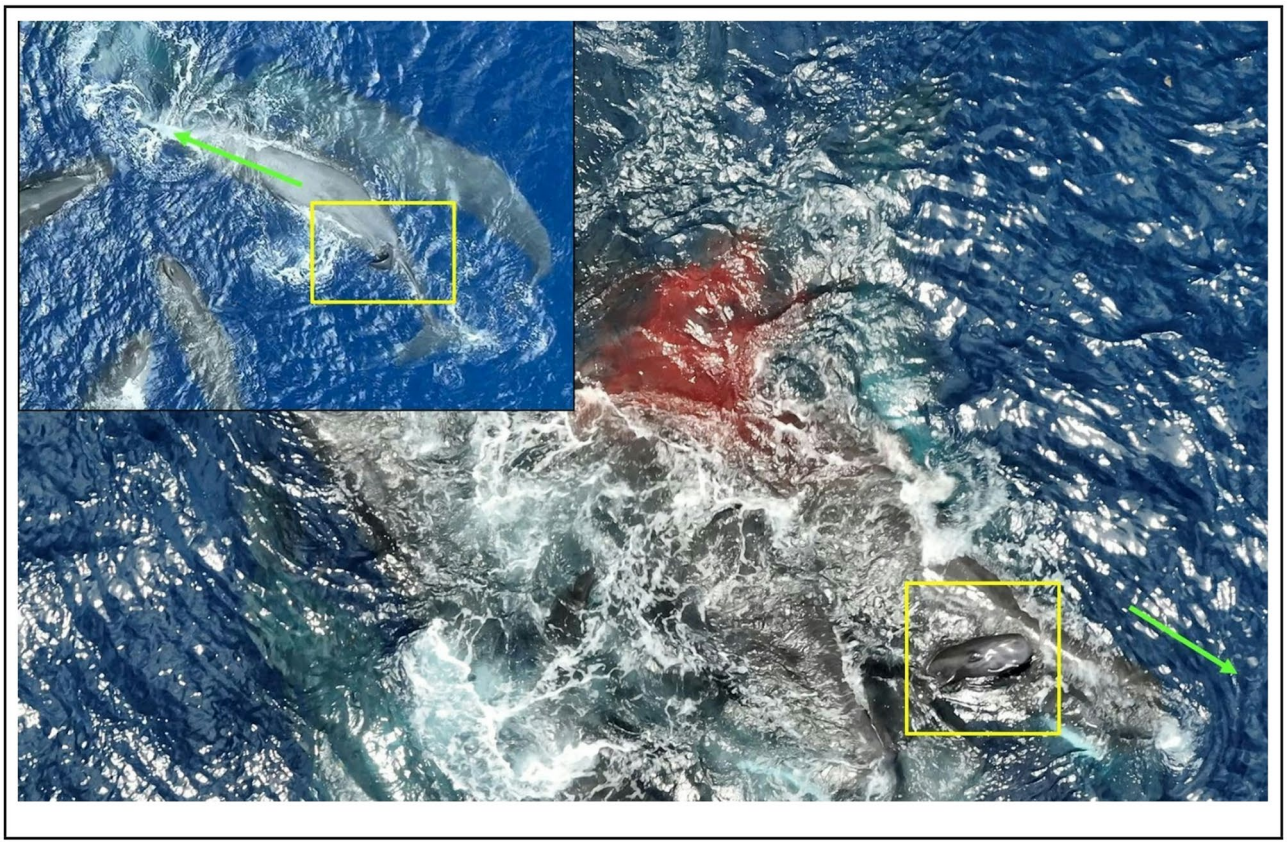


Fig. 3. Newborn sperm whale taking its first breath of air (bottom right highlighted by yellow box) while swimming to mother's head taken at 11:47 [00:01:15]. Note blood from birth still visible at the center of the image. Inset: flukes emerged first (highlighted by yellow box) as seen when mother rolled over approximately 35 min before birth. Green arrows denote the swimming orientation of the mother. Video of these moments available in **Video S4**.

escorting the newborn would open their jaws and jerk their heads towards the pilot whales; and in one case at 12:10:17 [00:24:32], one of the pilot whales rammed the nose of the adult female closest to the newborn (**Video S2**). The pilot whales engaged with the sperm whales in waves of 10–30 animals, despite larger numbers being nearby. The other pilot whales would often be logging at the surface or traveling slowly, within a kilometer of the sperm whales.

In addition to pilot whales, a school of Fraser's dolphins (~80–200 individuals first sighted at 09:18 [−02:27:45]) repeatedly approached the sperm whales across the same time period. There were no observable instances of direct physical contact between these species; although there were several close approaches. By 12:30 [00:44:15], the large cluster containing all the unit members and the newborn began to break up into smaller clusters separated by a few hundred meters. By 13:39 [01:53:15], the first of the sperm whales made a fluke-up foraging dive. This marked the transition between the highly social period leading up to and following the birth, to a return to foraging.

Following this birth on July 8, 2023, Unit A was not observed again until July 25, 2024, which is not uncommon as there are dozens of units that use the waters off Dominica. At this time, the then one year old newborn was observed off Dominica with both *Accra* and *Aurora*, the other young whales in the unit. There is a higher probability of sperm whales living to adulthood after they have survived the first year, based on documentation of first-year calf mortality in this community of sperm whales[40].

Acoustic behavior

An automated coda annotator[41] extracted 5,731 codas (31,364 clicks) from 3 h to 32 min of audio recordings, spanning 4 h and 21 min, covering the full length of the whale birth. Figure 6 plots the histogram of coda repertoire by rhythm and tempo type (**Fig. S4** breaks this down further across the timeline of this event). The predominant coda type produced during the event was the 1 + 1 + 3 coda (4,394 codas, over 78% are tempo type 3); followed by the second most produced coda the 4R (over 54% are tempo type 3; **Fig. S2**). **Fig. S3** shows the distribution of coda lengths in clicks, indicating that both common codas below 10 clicks, with a peak at 5 (common for this clan's dialect); as well as longer codas or coda creaks made up of 14 or more clicks, were produced during this event. During birth, there was a higher proportion of longer duration 1 + 1 + 3/5 codas, which shortened in duration after birth was complete, with a higher proportion of 1 + 1 + 3 or tempo 3 and 4 (Fig.

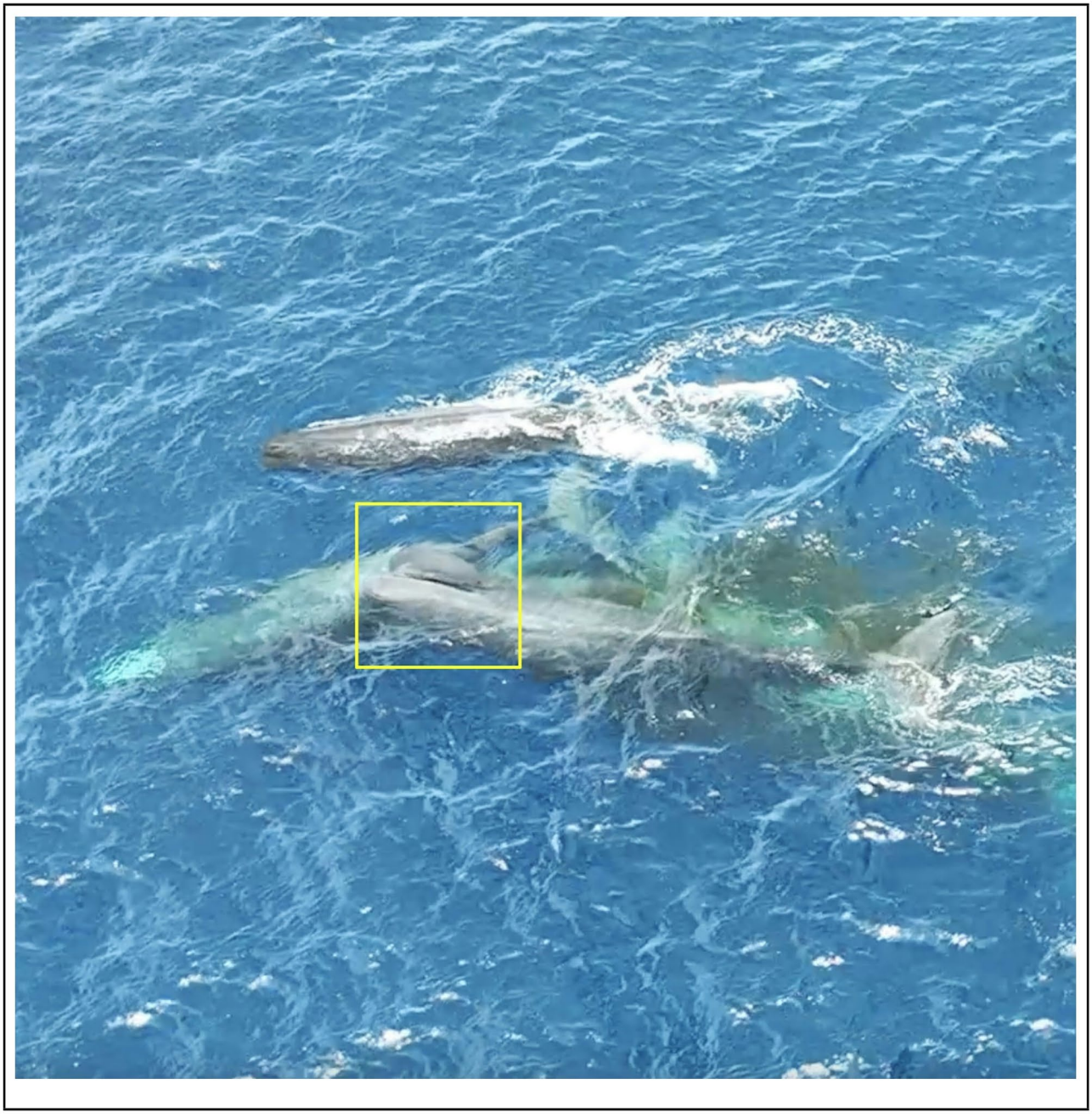


Fig. 4. Body of sperm whale newborn as it emerges from mother. White ventral blaze and genital slit of the mother are visible, showing a left occiput posterior position of the emerging newborn. As viewed at 11:42 [−00:04:45] (**Video S5**).

6). The vocal style, measured by how clicks are composed to produce codas, was then studied during the event to highlight potential deviations from the standard group's style. Comparisons of vocal style[42] indicated that large Variable Length Markov Chain (VLMC) distances appeared in codas made around significant behavioral events (Fig. 7), for example large variability in vocal style was detected just before and during the birth, and before and after interactions with pilot whales, which occurred after birth. There was a higher density of codas produced just prior to and after the birth of the newborn (Fig. 6). Both a- and i-vowel-like features as defined in[43] were detected in codas produced during the birth event (see Fig. 8). These coda vowel-like features were detected in far-field recordings from our research vessel, often several hundred meters away, suggesting that the codas' spectral characteristics were maintained over distances comparable to estimated distances over which conspecifics communicate[44]; and could have, therefore, been detected by interlocutors.

Fig. 5. Newborn sperm whale being lifted by several members of Unit A. A) DSLR image on the left taken at [00:08:29] from CETI 1. B) Umbilical cord can be observed in the drone image recorded at 11:48 [00:02:15] (**Video S6**). The fluke was still folded (yellow arrow) and the newborn lacked rigidity and was supported/lifted by other members of Unit A.

Lifting of the newborn whale by group members

A notable behavior observed was the lifting of the newborn whale by group members. This behavior was first noted within a minute after the birth and continued throughout the following three hours. There were several times when the newborn whale was nearly completely out of the water; both immediately after birth and during interactions with the pilot whales (Fig. 9).

Timing of events: laboring and birthing time

The first stages of labor, including the onset of early labor and dilation[45], were not documented in this study as observations began 32 min from the time the research team encountered the sperm whales until the observation of flukes emerging from the mother (taken as evidence of the second stage of birth, delivery). An increase of the intermammary distance is a valuable indication for predicting the onset of parturition in many cetacean species[46], which may explain the observation of multiple adults repeatedly diving under *Rounder* before any observable behavioral changes suggesting a birth was about to occur. Early labor and dilation could have been occurring for several days, as witnessed in a captive harbor porpoise (*Phocoena phocoena*)[46], in a study that included a multitude of measured parameters (rectal temperature, intermammary distance, progesterone levels, respiration rate, blubber thickness, weight, girth measurements, and different measures of food intake).

Active labor was only approximately 34 min between observing the flukes emerging and delivery. Given that we were able to observe the body of the newborn while still partially inside the mother, we were able to confirm that the body was in the left occiput posterior orientation. We could not determine the duration of the final stage of labor, between delivery and the passing of the placenta. While there were several observations of blood after the birth of the neonate (**Table S1**), we did not clearly observe when or whether the placenta passed (as some evidence suggests placental expulsion may occur hours after birth as noted in one instance for long-finned pilot whales (*Globicephala melas*)[47]. The umbilical cord was severed soon after birth, based on the movements of the mother, newborn, and the activity of their unit mates.

It took less than two minutes to clearly observe a breath from the newborn and three minutes to observe it attempting to swim. However, much of the time prior to that there was extensive activity amongst the adults that included lifting, pushing, and jointly squeezing of the newborn, so it is possible that it could have taken a breath or propelled itself prior to these clear observations. Throughout our observations, there was no release of meconium by the newborn. Over the course of the first two hours of the newborn's life, there was also no evidence of suckling, nor of peduncle dives alongside its mother or any of the other adult females, indicative of suckling[35]. Approximately two hours after delivery, the first of the adult female sperm whales made a fluke-up foraging dive. At this point, the other cetacean species had left, and the members of the unit had begun breaking up into smaller clusters at the surface and resuming typical foraging behavior. The smaller cluster which included the newborn remained at the surface the longest and included *Rounder* (mother), *Accra* (half-sister), and *Aurora* (young aunt).

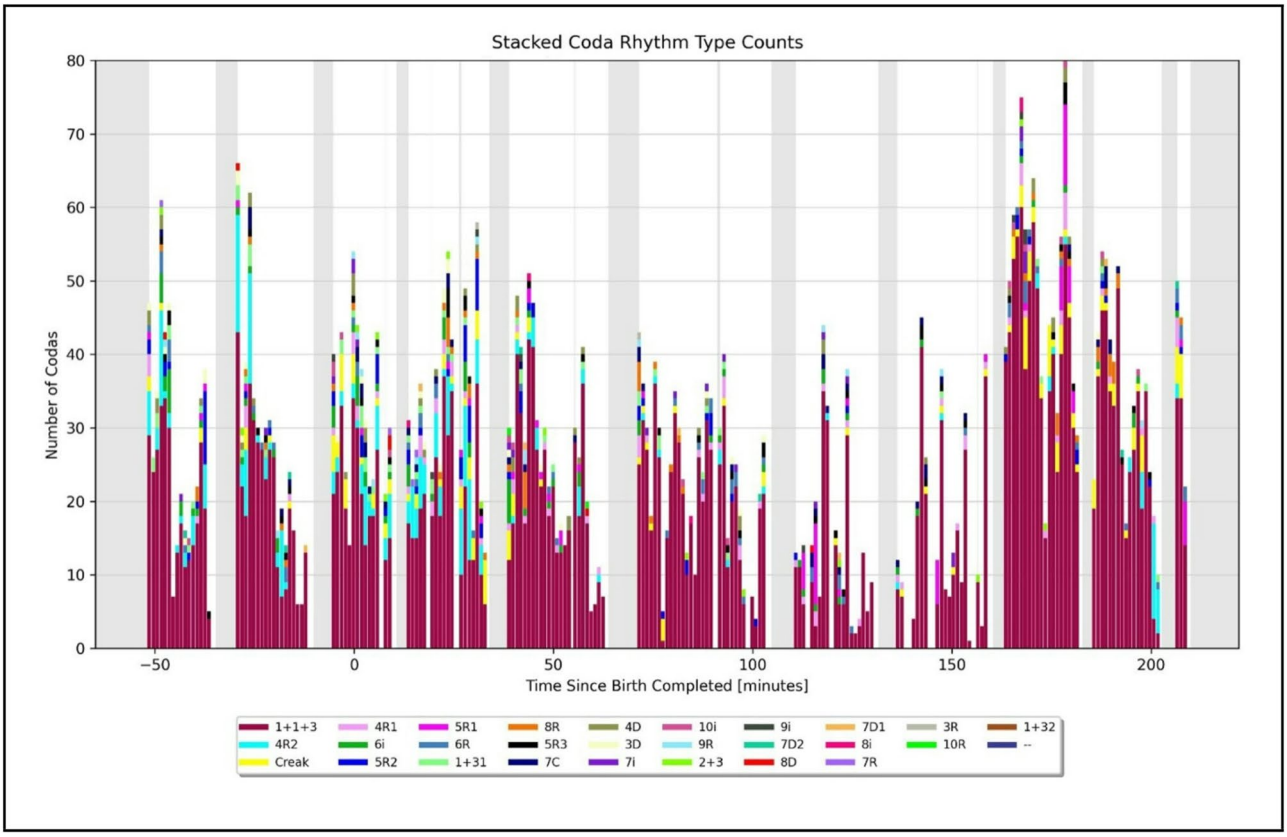


Fig. 6. Coda types over the duration of the sperm whale birth. Gray shading indicates the gaps between audio files (where audio data were not collected). Each bar summarizes a 1-minute window of audio. Non-overlapping rolling windows were used, and each bar counts codas that started within that window. The last window leading up to the end of each recording file is omitted (as < 1 min).

Discussion

Questions related to cetacean births have fascinated evolutionary biologists and scientists for centuries[48]. Some of this interest stems from the unique evolutionary history of cetaceans, as the return of early cetaceans to the oceanic habitat has inspired their nickname as the "poster child for macroevolution"[49]. Many unique evolutionary modifications took place for terrestrial mammals to become fully aquatic[50,51]. And, while evolutionary modifications can be examined anatomically and via genomic techniques[52], the social aspects of birthing can only be examined via direct observations. Up until now, observations of natural cetacean births have been notably rare, and this is the first study to contain detailed corresponding video, audio, as well as background information on the whales observed. Births in the wild have been documented in nine cetacean species, spanning a broad phylogenetic diversity (Fig. 10): sperm whales[8,9,11,12]; southern right whales (*Eubalaena australis*)[30], North Atlantic right whales (*Eubalaena glacialis*)[28,29], humpback whales (*Megaptera novaeangliae*)[18–22]; gray whales (*Eschrichtius robustus*)[31–33], belugas (*Delphinapterus leucas*)[26,27], killer whales (*Orcinus orca*)[23,24], false killer whales (*Pseudorca crassidens*)[25] and common bottlenose dolphins (*Tursiops truncatus*)[34] (See **Table S2** for comprehensive list). This limited information has made it challenging to understand the nature of cetacean births in the wild.

The most produced coda type during the birth event (1 + 1 + 3/Type 3) has been suggested to relate to the social identity of the Eastern Caribbean Clan to which these animals belong[53,54]. Furthermore, it has previously been suggested that overlapping codas could act as vocal grooming for social bonding amongst unit members[44]and the occurrence of these codas in the context of this highly socially affiliative event seems to support this hypothesis. Interestingly, the second most produced coda was the 4R (mostly 4R/Type 3), which has been proposed as a unit-level identifier for Unit A[53]; which further supports the social bonding during this family-focused event. Another relevant observation was the presence of distinct alteration of the group's vocal style in temporal proximity (Fig. 7) to salient events (e.g. at beginning and during the birth, and shortly before interactions with the short-finned pilot whales), signaling a departure from the group's basal style associated to instances requiring organization at the group level, whether to provide support during the birth itself, or protection after it.

In this study, we witnessed extensive lifting of the newborn by adult whales, and in some instances the newborn was almost completely out of the water (Fig. 9). This behavior was previously reported during births in several cetacean species including sperm whales[11], belugas[26,27], killer whales[23,24], false killer whales[25], North

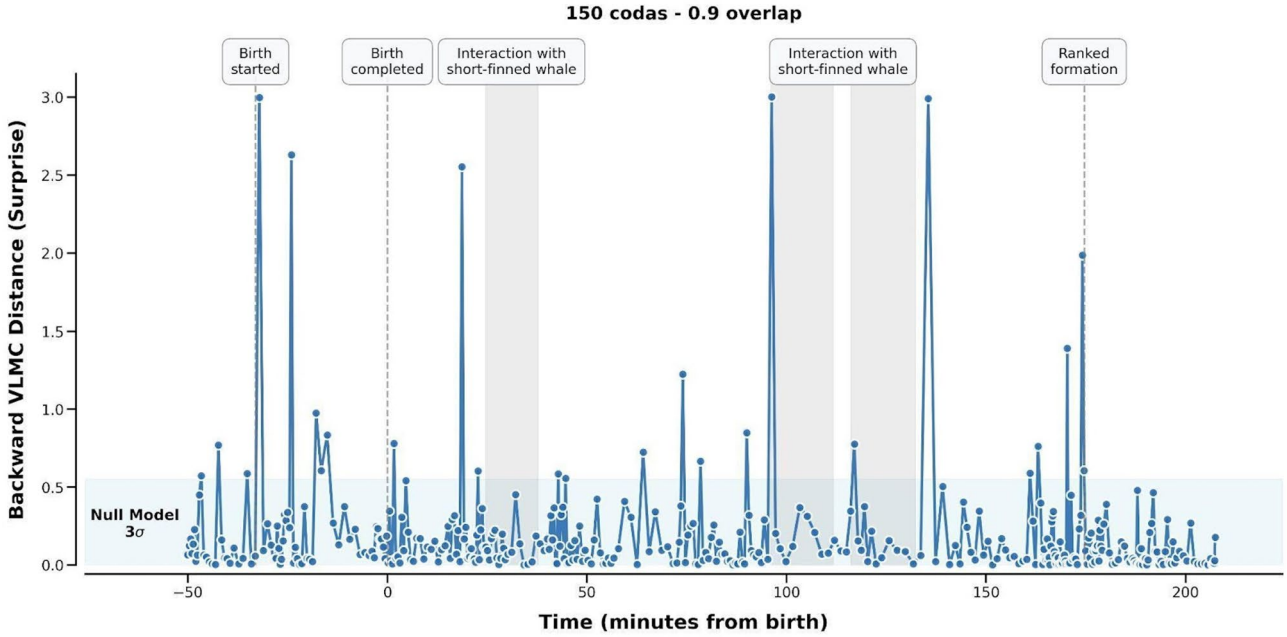


Fig. 7. Distance of instantaneous coda style during the birth event from the canonical vocal style of EC1 (obtained from legacy data under standard socialization conditions). Blue shadowed region on the bottom corresponds to three standard deviations away from canonical vocal style. Peaks correspond to strongly aberrant vocal style, and they correspond to specific events during the observation period. Distances between fitted VLMC models are measured using a modified KL divergence that accounts for the structural differences in subcoda trees obtained via the VLMC models[42].

Atlantic right whales[28,29], humpback whales[20] and common bottlenose dolphins (*Tursiops truncatus*[34] (**Table S2**). In addition, 'back-riding' of young calves has been reported in several additional mysticete species[55,56].

Phylogenetic distribution suggests that lifting behavior may be very ancient –older than the most recent common ancestor of toothed and baleen whales, > 36 million years ago (Fig. 10). Once early cetaceans transitioned to giving birth in deeper waters, assistance presumably would have been needed to prevent the newborn from drowning. In natural cetacean births documented in the scientific literature, lifting behaviors in mysticetes are restricted to interactions between the mother and the newborn calf (**Table S3**). By contrast, collaborative lifting behavior by multiple members of a social group has been observed in four odontocete species that span three taxonomic families (Delphinidae, Monodontidae, Physeteridae) (**Table S3**). The last common ancestor of these four highly social species is estimated to date back to > 34 million years ago, which might mark the evolutionary origins of this behavior (Fig. 10)[34].

It should be noted that newborn sperm whales are negatively buoyant[16]. In comparison to adults, neonates have relatively less oil in their spermaceti organ and/or junk[16,58], possess a lower percentage of body fat, and have smaller lungs relative to overall body size[59,60]. Research on the diving and acoustic behaviors of first year sperm whale calves demonstrate that calves have higher fluke stroke frequencies (i.e., they work harder) to counter negative buoyancy during ascents from deep dives, while adults glide more often during ascents[16]. It has also been shown that sperm whale stroke frequency scales negatively with body size[61]. As newborn sperm whales are negatively buoyant and their tail flukes are initially folded at birth (see below), lifting activity by clan members (Fig. 8; **Video S2**) may be required to prevent the newborn from sinking while also facilitating its first breaths. After millions of years of sperm whales' deep-water ancestry[62], there has likely been strong selective pressure on the newborn to quickly maneuver and stay afloat with the help of conspecifics.

In this study, the newborn sperm whale emerged in left occiput posterior orientation, with its flukes first. This enabled birth in close proximity and underneath its mother's peduncle (tailstock), known as the 'infant position'[63]. The newborn emerging in the same direction and orientation of the mother has been shown to provide hydrodynamic and protective benefits[64].

Marine mammals face daunting selective pressures regarding the anatomical and social aspects of birth underwater, complicating births relative to terrestrial mammals[65–67]. Over the course of cetacean evolution, as hind limbs disappeared and decoupled from the pelvis and vertebral column, the pelvic bones were eventually reduced to small splints of bone, and the birth canal could increase in size to accommodate a reversed birth orientation (head last, in contrast to many mammals which are born headfirst). Head last birth may reduce the risk of drowning[68–71]. In addition, this mode favored larger, precocial, neonates that can swim shortly after birth thus enhancing survival[67], although a few accounts have documented headfirst births in the wild in grey whales[31,3359]. also notes that headfirst occurs in about 1 in 25 births in cetaceans but does not provide evidence on how this was calculated.

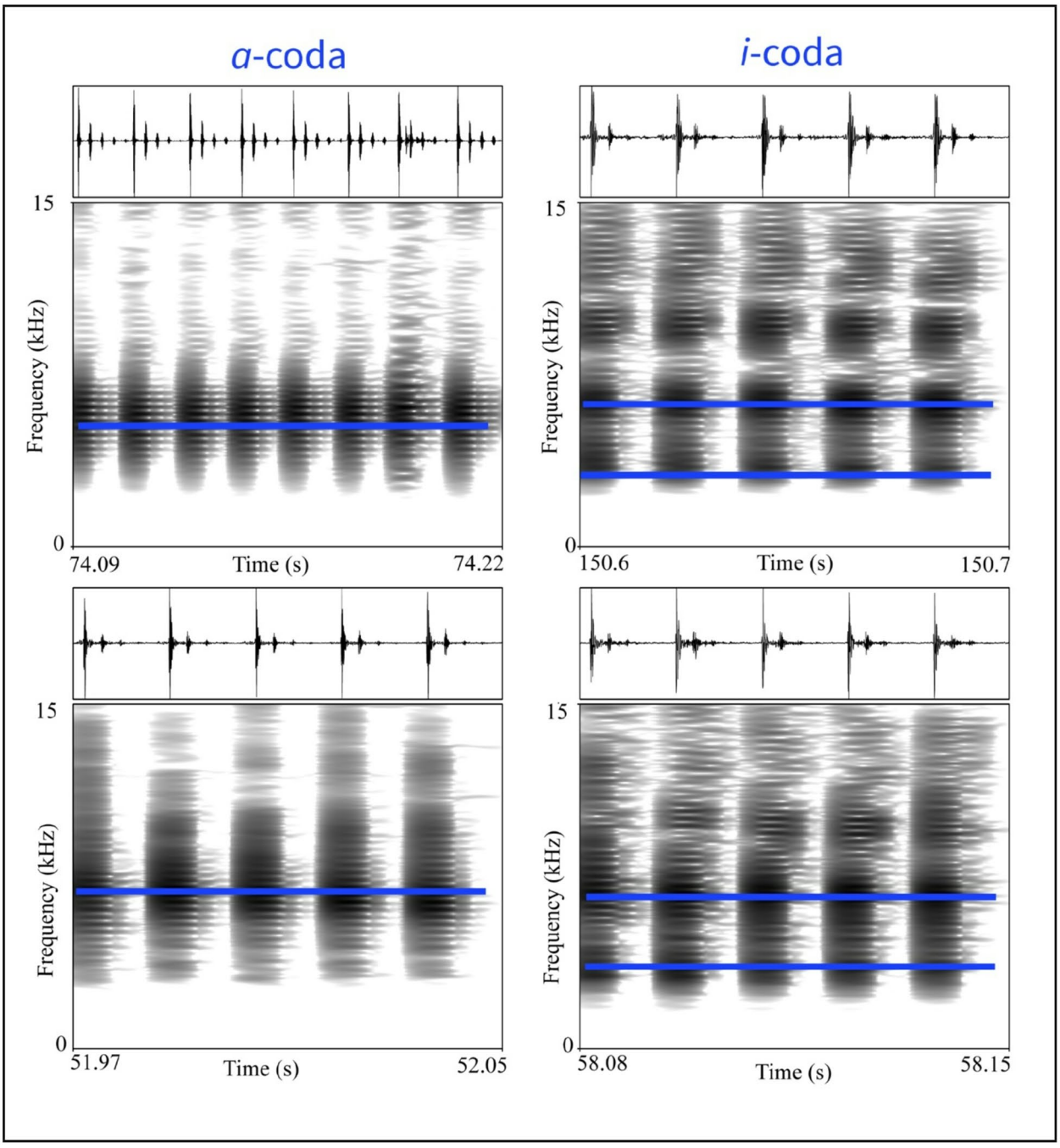


Fig. 8. Waveforms and spectrograms (0–15 kHz) of four codas with timing between clicks removed. The left two codas are of the a-coda vowel-like type (featuring one formant), the right two codas are of the i-coda vowel-like type, featuring two formants[43].

At previous sperm whale birth observations, Weilgert and Whitehead[8] witnessed dolphins (thought to be *Tursiops* sp. or *Pseudorca crassidens*) within 150 m of the whales while Gambell et al.[9] noted five adult sperm whales present as well as a false killer whale swimming around the calf. That study also mentions an additional sperm whale birth event in 1966 "where a whale was surrounded and supported by other animals in a group of 24 sperm whales. A very small calf appeared, and all the time the sperm whales were surrounded by a vast school of dolphins which kept a continuous circle around them." In all previous sperm whale birth observations, the birth took place while the mother was within a large group of other sperm whales, and all reports, except[11] note the nearby presence of other cetacean species (Table 1).

In this study, we observed large schools of both Fraser's dolphins as well as short-finned pilot whales (see Figs. 9 and 11). Short-finned pilot whales and dolphins appeared at 12:04 [00:18:15] and often surrounded the cluster of sperm whales including the neonate. While the dolphins came and went, the school was so large that

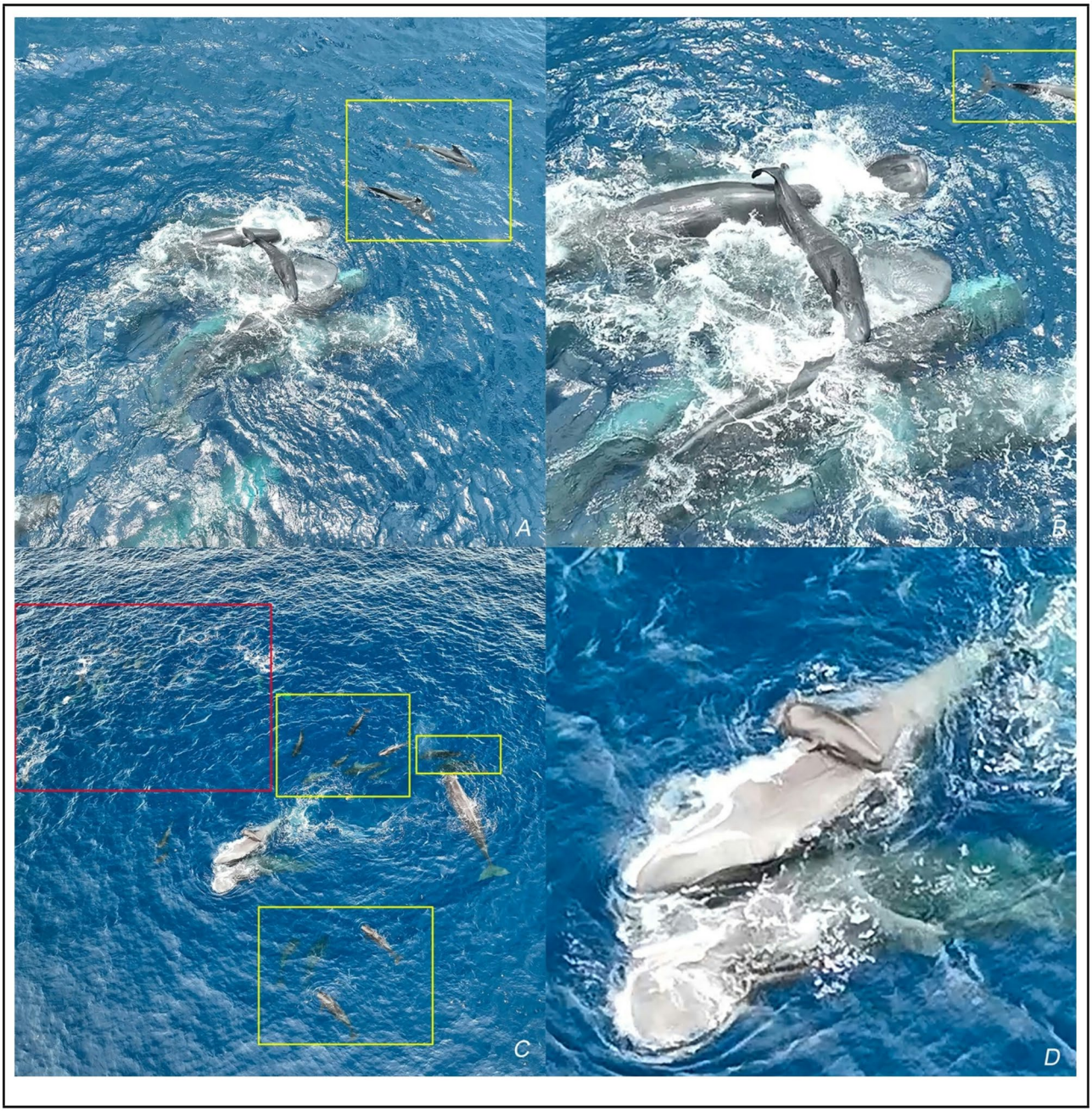
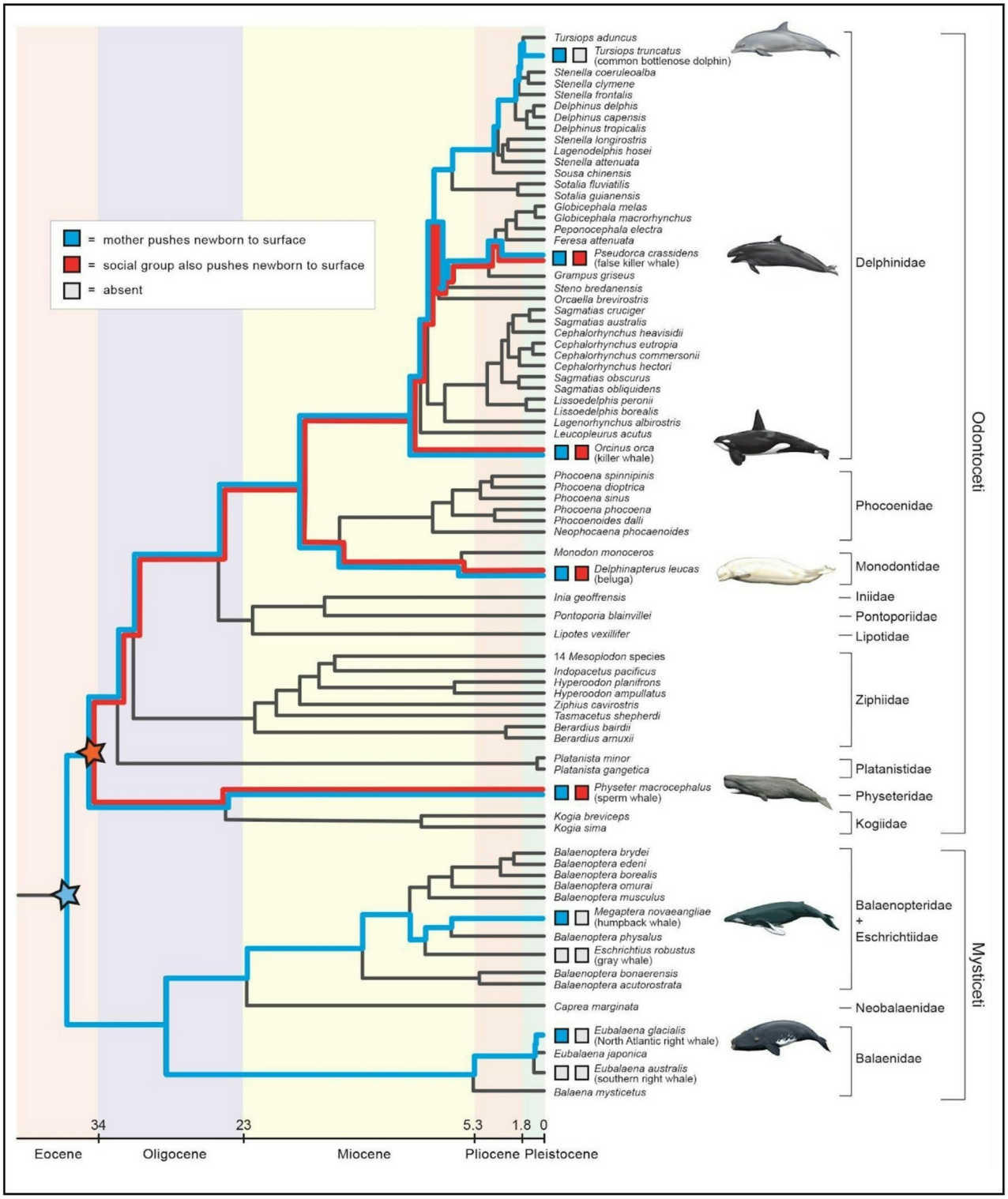


Fig. 9. The newborn sperm whale was lifted out of water, while short-finned pilot whales were within one adult body length (yellow boxes); and a school of Fraser's dolphins were present farther outside of the pilot whales (in the top left of the image, red box). C and D As observed at 13:38 [01:52:15].

dolphins were often on multiple sides of the sperm whales but at a greater distance; the pilot whales interacted often with the cluster of sperm whales which included the newborn. In some instances, pilot whales dove under the sperm whales and the newborn.

Pilot whales have been previously reported to "harass" sperm whales[72], but whether they present a threat to sperm whales is still unclear. Other accounts have made note of aggressive[73] or harassing[72] behavior of pilot whales upon sperm whales, but no predation has been reported[73]. notes that social play by the pilot whales cannot be discounted. This study's observations are consistent with those of[74,75] that could be interpreted as aggression or harassment. This includes observations of open jaws by sperm whales, erratic changes of orientation and surface behavior, and is particularly noted at one instance when a pilot whale rammed into the newborn's nearest neighbor (**Video S2**). Yet, this extensive interaction also ended with the pilot whales not harming the neonate. There are also numerous anecdotal stories of dolphins coming to the aid of distressed conspecifics[76] and published reports of other cetaceans, such as humpback whales, aiding distressed marine



vertebrates[77]. These anecdotal stories and brief observations call for more rigorous, data-driven approaches to analyze complex behavioral interactions among species using drone footage.

Compared to the highly social female social units, most mature male sperm whales live relatively solitary lives at higher latitudes[78,79]. Among mammals; however, sperm whales are a rare species in which there are examples of long-term bonds among mature males. These relationships cannot be explained by kinship, and clear benefits to reproduction are not apparent[80]. Before forming these 'bachelor groups', juvenile males disperse from their highly social natal units in their early teens. Instead of leaving of their own volition at sexual maturity, juvenile males appear to be abruptly socially isolated by the adult females in their natal unit after their mother gives birth to a new calf[36]. While the social relationships with the adult females diminish dramatically, the final departure from the unit can take several years[36]. In the present study, the young male *Allan*'s social involvement in Unit A declined after his mother, *Lady Oracle*, gave birth to *Aurora* in 2016 (when *Allan* was only 8 years

◀**Fig. 10**. Ancestral reconstruction showing where behaviors related to assistance at birth may have originated: blue = 'mother sometimes pushes newborn to the surface' and red = 'members of the social group sometimes help the mother push newborn to the surface'. The timetree for Cetacea is according to[57]. The colored stars indicate the time points where the two behaviors evolved, assuming that each behavioral trait evolved just once, with subsequent losses in some species (*Eschrichtius robustus*, *Eubalaena australis*, *Tursiops truncatus*). Double gray boxes are shown for the two species where births have been observed in the wild, but with no lifting of the newborn to the surface. The remaining species with no observations of birth in the wild have no squares, as the character states are unknown. Note that the evolution of these behavioral traits may be highly correlated with the social structure of cetacean species, and these traits might have evolved convergently multiple times within Cetacea. For 'mother sometimes pushes newborn to the surface', an equally parsimonious mapping includes three independent derivations of this trait (in the common ancestor of Odontoceti, in *Megaptera novaeangliae*, and in *Eubalaena glacialis*).

Fig. 11. Examples of sperm whales intermixed with other cetaceans, short-finned pilot whales (**A**) and Fraser's dolphins (**B**), during the birth event.

old). *Allan* is *Rounder's* younger, half-brother and the newborn's uncle. Despite being socially isolated from Unit A leading up to the birth reported here, it is interesting to observe that *Allan* was a part of the social activity surrounding the birth. *Allan* was present in the cluster that included the entire unit for at least an hour during labor before the birth and was involved in highly social interactions immediately after birth. *Allan* being present at the birth is consistent with earlier observations of another juvenile male in transition away from another social unit observed off Dominica, Unit F. In that case in Unit F, the juvenile male, *Scar* (whale# 5727), associated with his new sibling, *Tweak* (whale# 6070), for at least two years, including playing a role in babysitting while their mother made deep foraging dives[5]. These behaviors were recorded even after being socially ostracized by adult females in Unit F, as evidenced by a dramatic reduction of social relationships between *Scar* and the adult females in his natal unit[36].

While our observations did not include shark sightings, two other sperm whale birth events[12] documented the presence of sharks, and in one case, sharks were observed feeding on afterbirth from the sperm whale[9]. There are many possible avenues to hypothesize or speculate around the presence of sharks at cetacean births. The presence of other cetacean species may act as a protective barrier to sharks. The afterbirth might also attract schools of fishes that are of predatory interest to sharks and/or other cetacean species. It is also possible that the afterbirth attracts sharks or that sharks sometimes directly attack newborn sperm whales. This may also explain the close proximity of the Unit of sperm whales to the newborn sperm whale. Shark populations in the Eastern Caribbean and worldwide have drastically declined in recent decades[81], so while this threat may have lessened since the era of large-scale whaling activities, it may still play a role in the cultural dynamics of sperm whales.

Conclusions

This first-of-its-kind dataset of extensive aerial footage of a sperm whale birth, combined with synchronized underwater audio recordings, offers unique insights into a key biological feature of sperm whales. Our results show commonalities with births of other cetacean species including (1) lifting behavior of the newborn; (2) extensive vocalizations at birth showing clear differentiations at various stages of the birth; (3) other cetacean species being present.

This study also opens new questions and hypotheses regarding sperm whale births and cetacean births more generally: Are vocalizations and vocal coordination in highly social cetacean species a necessary feature to give birth successfully? Does calf survival increase with the involvement of other whales present? All previous observations of sperm whale births have multiple whales present[8,9,11,12], so it is possible that multiple whales are required for successful birth to prevent the newborn from potentially drowning or for general protection/aid. This also yields information on cooperative behavior at birth, where this type of behavior has been exhibited in cetaceans. The curved flukes (Fig. 5a) and the **Video S3** show that assistance was needed before the newborn could swim properly. Our study opens the window to data-driven, machine learning and computer vision approaches that can be employed to quantify complex social network behaviors.

Methods

Study site

The sperm whales were encountered off the leeward, western coast of Dominica in the Eastern Caribbean during operations of Project CETI which uses two different vessels. CETI-1, a 40-foot (12.2 m) catamaran, from which drone flights, photo identification, and behavioral observations were performed; and CETI-2, a 26-foot (~ 8 m) a rigid-hulled inflatable boat, from which photo-identification and acoustic recordings were undertaken. Initially, the unit of sperm whales was located acoustically using directional hydrophones aboard CETI-2, then encountered by both boats by 10:40 [−01:05:45] at the surface (See **Table S1**). The research team observed from several hundred meters away, with engines off.

Data collection

During this event, we utilized multiple data collection techniques. The dataset includes audio and video data throughout the birth event, in addition to photographic (two Canon DSLRs with 200–300 mm lenses) and behavioral observations collected by experienced observers (Led by SG with over 20 years of experience studying sperm whales off Dominica) onboard the research vessels. Aerial video was collected by two synchronous quadcopter drones (DJI-Mavic-3) which maintained an altitude of at least 25 m above the surface; underwater audio was collected using a single omnidirectional hydrophone (C75 Hydrophone, Cetacean Research Technology) connected to a digital acoustic recorder (MIX6 Pre, sampling at 96 kHz at 16 bit), as well as additional photographs collected for photo identification and behavioral documentation from the research vessel. Observations were stored in a custom iPad app.

Ethics declarations

Project CETI's research is conducted under scientific research permit # LS 27–200-21 to Project CETI Dominica granted by Dominica Fisheries Division of the Ministry of Agriculture, Fisheries, Blue and Green Economy and all methods were carried out in accordance with relevant guidelines and regulations. All research protocols (drone research and data collection) were approved under Harvard University's IACUC Protocol ID # 21-02-379-1.

Analysis

Photo-identifications were analyzed using Flukebook[82]. Codas were typed using custom MATLAB annotation tools[41] and categorized based on[83] and vowel-like features are defined based on[43,45]. The data from various data

collection platforms were synched to conservatively within 1 s (approximately within 20 milliseconds); and accompanying DSLR photographs to the nearest second.

Vocal style analysis

To analyze changes in vocal styles during the birth event, we utilized a methodology based on Variable Length Markov Chain (VLMC) introduced in previous work[42]. We constructed a series of overlapping sliding windows from the birth audio recordings, each containing n = 150 codas with a 90% of overlap (i.e. each consecutive window shares 135 codas with the previous one). For each window w, a VLMC model Xw was fitted to capture the probabilistic structure of coda vocalization within that window. To assign a time to each window, we used the average starting time of the codas it contains. For every pair of consecutive temporal windows, we then computed the distance between the corresponding VLMC models Xw and Xw + 1 using standard tools introduced in[42]. This captures the variation of the vocal repertoire across time. We applied the VLMC model to legacy coda data from Unit A under standard social conditions to establish a baseline for comparison. To assess the significance of the observed distances in the birth event data, we similarly computed distances between consecutive VLMC models Xw and Xw + 1 using legacy data from days with sufficient coda recordings (i.e. more than 250 codas within the day). After computing distances for more than ten different days, we generated confidence bounds to determine the reliability of our measurements. The resulting confidence bounds, along with the distance measurements from the birth event data, are reported in Fig. 9, providing a reference for evaluating the variation in vocal repertoire over time.

To quantify the significance of the main identified events (start of recordings, start of birth, birth complete, first pilot whale sighting, after pilot whales when animals start to fluke, end of recordings), we compared the properties of the detected codas before and after each event (**Figure S5**). This comparison was performed by extracting features from the detected codas and measuring how similar are the empirical probability density function (PDF) of each feature before and after each event. To this end, we considered as features the temporal density of the codas, the coda type, the coda inter-pulse interval (IPI) and the coda inter-click interval (ICI) between the different click pairs. Each of the above features was averaged over a time window of 60 s. A normalized histogram was then calculated to obtain the empirical PDF of the accumulated data for the considered observation times: before and after each event. To compare the empirical PDFs we use the Kullback-Leibler Divergence (KLD) bound

$$D_{\mathrm{KL}}\left(P \,||\, Q\right) = \int_{x \in S} P\left(x\right) \log\left(\frac{P\left(x\right)}{Q\left(x\right)}\right) dx,$$

.

where P and Q are two PDFs. The KLD is a measure for the conditional entropy between two distributions and its value increases the more distinct P and Q are. By averaging, for each event, the KLD for the 'before' vs. 'after' and the 'after' vs. 'before' time observations, we received an indication of the impact of each event on the characteristics of the coda vocalizations. The KLD for each feature were then summed in relation to each event.

Phylogenetic mapping of behavioral traits

Published accounts of natural births in cetaceans are limited to just nine species with few observations per species[17]. Phylogenetic mappings of helping behaviors at birth (presence versus absence) were inferred by equally-weighted parsimony[84] on a time-calibrated phylogenetic hypothesis for Cetacea[57]. The phylogenetic distributions of 'mother sometimes pushes newborn to the surface' and 'other members of social group also may push newborn to the surface' are spread across the cetacean family tree, suggesting deep evolutionary origins for these traits. Multiple independent derivations of these traits cannot be discounted, however, given the limited information currently available (just nine species coded), few published observations per species, as well as potential for correlated gains and losses related to evolutionary changes in social structure within Cetacea.

Data availability

Data is available in the main text or the supplementary materials as well as on https://www.projectceti.org.

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Author contributions

Drafted manuscript: SG, DFG, JG and JDP. Performed acoustic analysis: RD, GP. Performed vowel-like feature analysis: GB. Performed phylogenetic character mapping: JG. Involved in onboard observations and collection of data of sperm whale birth: YA, RB, CB, JDP, KG, SG, DG, DFG, OH, YM, SP and MS-H. Reviewed and contributed to manuscript: JA, ZB, RB, CB, GB, SB, MMB, SD, OD, SdH, JD, JDP, RD, RD, DG, DFG, SG, OH, AH, MI, NJ, LKC, AK, AL, ML, AM, PM, YM, SP, OP, GP, SP, ER, DR, MSH, AS, PS, DT, AT, PT, DMV, RJW.

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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