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ARTICLE

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Satellite image survey of beluga whales in the southern Kara Sea

Peter T. Fretwell[1] | Hannah C. Cubaynes[1] | Olga V. Shpak[2]

[1]British Antarctic Survey, Cambridge, UK

[2]Independent scientist, Ukraine

Correspondence
Peter T. Fretwell, British Antarctic Survey, High Cross, Madingley Road, Cambridge, CB3 0ET, UK.
Email: ptf@bas.ac.uk

Abstract

The use of satellite imagery to find, count and monitor whales in remote and hard to access areas has shown some promise, but few satellite studies have, as yet, provided substantial conservation outcomes. Recent studies have shown the ability of very high-resolution satellites to detect and count previously surveyed populations of belugas and narwhals in Canada. Here we describe the detection of a large aggregation of a poorly surveyed population of belugas in the southern Kara Sea, Russia, in a region where Soviet whaling is known to have had a heavy toll on belugas. We counted over 1,100 surface belugas using very high-resolution satellite imagery. As only an unknown portion of the belugas can be seen on the surface, accurately converting the surface count to an abundance estimate will need further study, but using the analog of aerial surveys we estimate that this aggregation is between ~1,150–2,870 individuals. Although the species is not currently considered endangered, concern over belugas future population trends is increasing, as the species is reliant on Arctic sea ice, which is rapidly declining due to climate change. This study shows the utility of satellite imagery to discover and monitor new and little-known cetacean populations.

KEYWORDS

Baydaratskaya Inlet, beluga, *Delphinapterus leucas*, imagery, Kara Sea, VHR, whale

1 | INTRODUCTION

The beluga whale (*Delphinapterus leucas*) is a small to mid-sized (up to 5.5 m) cetacean of the Monodontidae family. The species ranges from the Arctic to sub-Arctic, and most populations migrate seasonally between the margin of the sea ice zone in winter and coastal waters, after coastal sea ice has melted in summer (Kleinenberg et al., 1964; O'Cory-Crowe et al., 2018; and others). In the Russian Arctic, belugas permanently or seasonally occupy all northern Seas (Boltunov & Belikov, 2002; Kleinenberg et al., 1964), but, except for the White Sea population, remain poorly studied. Soviet whaling records show that the White, Barents, and Kara Seas were heavily harvested, (Alekseeva et al., 2019; Kleinenberg et al., 1964; Ognetov, 1999), with up to 6,000 whales taken per year. As there have been no comprehensive studies in the area, international experts currently agree that there is not enough information to delineate beluga stocks within Barents-Kara-Laptev Seas region (Hobbs et al., 2019). Some of these stocks may have been severely depleted in the 20th century and their recovery potential is unknown.

At present, development of hydrocarbon extraction industries, as well as increase in ship traffic, pose challenges to the belugas in the waters of western and central Siberia. Baydaratskaya Inlet in the southwestern Kara Sea (Figure 1) has historically been known as a place of beluga concentration in summer, with most sightings recorded in the northwestern part of the inlet (Kleinenberg et al., 1964). Ognetov and Potelov (1984) mentioned a dramatic decrease in beluga numbers in Baydaratskaya Inlet after a period of intensive vessel-based harvest in 1954–1966. In 1977–1980, another attempt of vessel-based harvest (with unknown success) was also undertaken in the region. Belugas are philopatric to their summer grounds, where they give birth and raise the young (O'Corry-Crowe

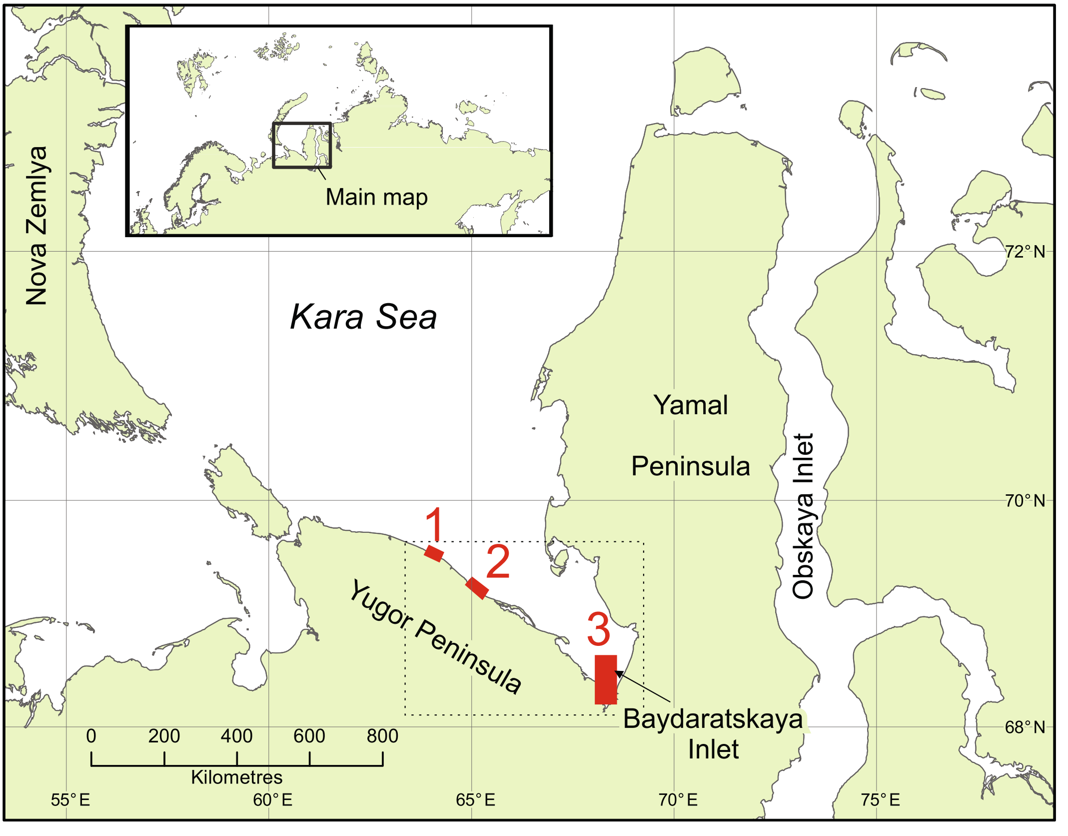

FIGURE 1 Location map: red rectangles show the areas of coastline with clear imagery in July/August with a calm sea state (see methodology); the area covered in Figure 2 is shown in the dotted box.

et al., 1997). Once abandoned, a summer ground may not be revisited by belugas for long periods of time. Human development may also degrade beluga's habitat quality. At present, two gas pipelines from Bovanenkovo extraction site are laid across Baydaratskaya Inlet, and two of their four subpipes have floated to the surface and required major repair work (https://oilcapital.ru/news/transport/22-11-2019/razbushevalis-truby-v-karskom-more, https://www.gazprom.ru/about/subsidiaries/news/2020/october/article515979/). Work to restore the pipeline and secure it by burying it in a trench on the seabed could disturb belugas and pollute their habitat.

Arctic cetaceans also face impacts from ongoing climate change in the Arctic region, which is resulting in substantial reduction in the seasonal extent and thickness of sea ice (Comiso, 2012; Stroeve et al., 2012). Belugas in the Kara Sea are thought to occur in the marginal sea ice zone in winter (Boltunov & Belikov, 2002; Hobbs et al., 2019), suggesting a strong connection with sea-ice influenced habitat. In winter, belugas are dependent upon ice-associated fish species such as Arctic cod (*Boreogadus saida*). Changes in the distribution and characteristics of sea ice will likely result in redistribution of prey species (Haug et al., 2017; Laidre et al., 2015). However, the potential costs or benefits to belugas of such climatic changes are currently not known.

Recent studies on the use of very high-resolution (VHR) optical satellite imagery have shown promise in the identification and monitoring of larger whale species (Corrêa et al., 2022; Cubaynes et al., 2019; Fretwell et al., 2014; Hodul et al., 2022). A recent paper (Charry et al., 2021) based upon the well-studied Monodontidae stocks in Canada has shown that 30-cm resolution VHR satellite imagery can be used to detect and count surface beluga and narwhal populations. Satellite imagery is cost-effective (current cost ranges between US\$3–\$30 per km^2, see https://www.maxar.com/products/satellite-imagery) especially in remote areas, which are difficult to access by traditional survey techniques. Thus, monitoring of Arctic cetacean populations such as belugas, by satellite and how they adapt to their changing environment could be beneficial.

After opportunistically sighting belugas in the area from VHR satellite imagery in 2020, we instigated a study with the aims of surveying belugas on the eastern side of the Yugor Peninsula and in Baydaratskaya Inlet in the southern Kara Sea using VHR satellite imagery, and to attempt to collect information on the size of the aggregation to see if the species has returned in number to this area. As only a portion of the area is covered in the archive by suitable satellite imagery, any figures reported here should be considered a minimum estimate (see Discussion).

2 | METHODS

2.1 | Study area

Our study area is the southern Kara Sea, in the Russian Arctic. The locations and coverage of the study area are shown on Figure 1 and comprised two regions on: (1) the eastern shore of the Yugor Peninsula and (2) in the inner part of Baydaratskaya Inlet. The southern Kara Sea equates to an area of around 30,000–40,000 km^2, depending on where the exact boundaries of the area are drawn. The region has never been systematically scientifically surveyed for beluga whales. The area was chosen due to the chance discovery of beluga whales by the authors while searching for walrus, *Odobenus rosmarus* haul outs in satellite imagery off the eastern Yugor Peninsula (Figure 2 area 1). As information on the locations and timings of beluga whales in the area is unavailable, we targeted satellite images taken in July, the same month in which whales were originally observed in the area on imagery from a previous walrus survey.

2.2 | Imagery

We used imagery from two sources. The first was through the ESRI World Imagery layer (https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9 accessed December 2020), a freely accessible resource

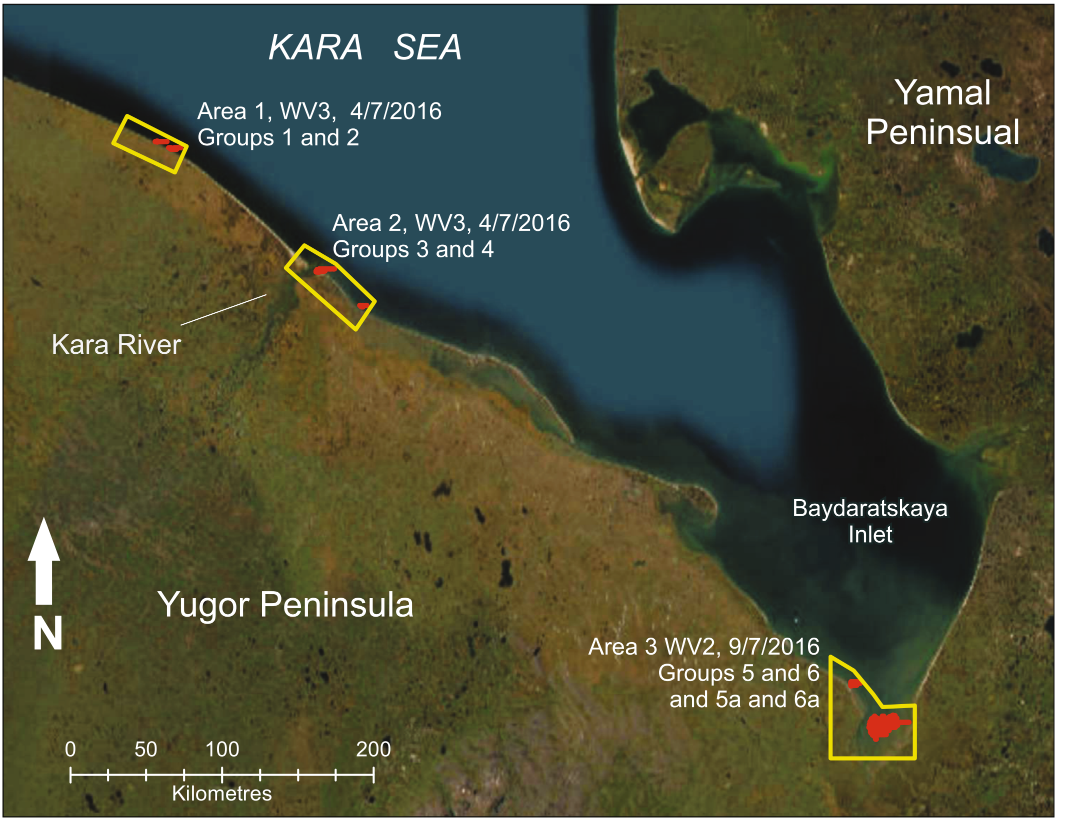

FIGURE 2 Satellite map of the study area showing the locations of belugas found in the VHR imagery as red dots and the areas of suitable imagery as yellow boxes, with the image dates (day, month, year) and satellites used to count each group of whales. We assessed two images of Area 2, taken 73 s apart, the counts from these two images are classed as groups 5 and 6 from one image and groups 5a and 6a from the second image.

available either in a web browser or Web Map Service (WMS) that feeds into ArcGIS. This image layer is composed of a single layer of imagery and the user has no control over the date and timing of the imagery in the browser. This meant that only around 15% of the coastline, around 107 km of a coastline length of ~715 km, had suitable imagery. Most of the coastline had imagery that was either at the wrong time of year (i.e., in May or June before the sea ice had receded northwards) or with poor weather conditions (e.g., cloud cover, strong winds, or where the sea-surface was too rough to see whales, as calm seas with a Beaufort sea state of 1 or 2 is necessary to accurately identify whales; Cubaynes et al., 2019) and therefore not suitable for counting belugas. The three areas along the coast of the southern Kara Sea with suitable imagery are shown in Figure 1. For our study, we viewed the imagery and counted whales in ArcGIS Desktop version 10.6 (Environmental Systems Research Institute, Redlands, CA).

We also acquired two images from Maxar technologies' archive (https://discover.maxar.com/): a WorldView-2 image (ID 103001005 AD12400, July 9, 2016) and a WorldView-3 image (ID 104001001D6F2200, July 4, 2016). Sourcing the underlying imagery gives more flexibility on dates and acquisition times and allows the user to adjust contrast levels and satellite band combinations, which is not possible in the ESRI browser.

These two individually sourced images covered areas 1 and 3 (Figure 1) and had a coverage of 152 km^2 and 2,550 km^2 of sea, respectively, of which 123 km2 and 1,652 km2 overlapped with suitable imagery from the ESRI World Imagery layer. The image that covered area 1 was the same image in the ESRI World Imagery compilation, and the image that covered area 3 was taken 73 s before the image used in the compilation as part of a stereo pair and was of similar resolution and quality, and extended more to the west. Therefore, we were able to count the imagery in Baydaratskaya Inlet twice within a short time of each other. Apart from this westward extension of area 3 only the areas where images overlapped were counted for whales.

2.3 | Analysis: Counts

The belugas were counted manually in ArcGIS Desktop version 10.6 in all images, by one expert counter at a scale of 1:1,000 using shape, color, and size. There is usually a slight inconsistency between manual counters when identifying animals in VHR satellite imagery (Bamford et al., 2020; Bowler et al., 2020; Cubaynes et al., 2019) and this difference depends upon the image quality, sea state, and size and clarity of the object being counted ability and/or the training of the observer. We tested the variance between counters two counters (P.T.F. and H.C.C.) on a subset of the data; areas 1 and 3 with just over 1,000 whales and found only a variance in the total count of 0.4%, with errors of assignation of 4.0% for the 31 cm imagery and 5.1% for the 50 cm imagery. So, for this preliminary count we used a single counter (P.T.F.), experienced in labeling cetaceans in VHR satellite imagery.

2.4 | Analysis: Comparison of ESRI World Imagery and raw imagery

The satellite images freely available in the ESRI World Imagery layer cannot be manipulated like the raw images available from the satellite operator, where the color band combination, contrast and brightness can be changed, but come at a cost. Therefore, we compared the ability to detect belugas in the VHR satellite imagery available on the ESRI World Imagery layer versus in the raw images, using the two images reviewed for area 1 (see Imagery).

2.5 | Conversion of surface whales to population numbers

At present, there has been no ground truthing of belugas comparing counts from VHR satellite imagery to counts from boat-based or aerial surveys, to calculate the accuracy of our satellite counts, or what percentage of the population the satellites can see on the ocean surface. Several studies have tried to assess the availability bias from aerial surveys, but results vary depending upon turbidity, ranging from 40% to 55% of belugas visible at the surface at any one time (Boyd et al., 2019; Kingsley & Gauthier, 2002; Richard et al., 1994). The most recent study by Boyd et al. (2019) in Cook Inlet, a turbid environment, had a median of bias of 54.8%, with a range between flights of 48.6% and 72.3%. An alternate method of estimating availability bias using satellite tagging and tracking rather than aerial survey in Hudson Bay (Matthews et al., 2017) suggests that animals spend 70%–100% of their time within 0–5 m of the surface. It seems probable that in optimal sea conditions (flat calm, clear water) a downward looking satellite image may see most whales within 5 m of the sea surface; however, this has yet to be tested. We use a combination of these value ranges, depending upon the behavior of whales seen in the satellite imagery, to estimate population numbers (see Results).

3 | RESULTS

3.1 | Counts

Three groups of belugas were identified along the coast of the Yugor Peninsula (areas 1 and 2), totaling 213 whales, all the whales were within 500 m of the coast (Table 1). At the southeastern end of the Yugor Peninsula a large bay, here termed Baydaratskaya Inlet contained 934 belugas (area 3; Table 1).

TABLE 1 Numbers of whales counted in each group with average orientation of the whales. Subtable A shows whales counted from ESRI World Imagery (https://www.arcgis.com/home/webmap/viewer.html accessed December 2020). Subtable B shows whales from groups 5a and 6a counted from a single image acquired directly from Maxar Technologies. For the whales swimming in a set direction, we applied the availability bias correction from Matthews et al. 2017 (70%–100% availability), and for the groups swimming in random directions we applied the availability bias correction from (40%–55% availability).

Subtable	Area	Group	Count	Estimate	Swim direction	Imaged	Size
A-ESRI Worldview imagery	Area 1	Group 1	25	25–36	SW	WV3 (ESRI)	152 km^2
		Group 2	47	47–67	SE	WV3 (ESRI)	
	Area 2	Group 3	125	125–178	SW	WV3 (ESRI)	213 km^2
		Group 4	16	29–40	random	WV3 (ESRI)	
	Area 3	Group 5	73	73–104	SE	WV2 (ESRI)	378 km^2
		Group 6	716	1,301–1,790	random	WV2 (ESRI)	
B-imagery acquired from MAXAR	Area 3	Group 5a	213	213–304	SE	WV2 (MAXAR)	2,550 km^2
		Group 6a	721	1,311–1,802	random	WV2 (MAXAR)	

The two most westerly of the beluga groups (groups 1 and 2 from area 1), containing 25 and 47 visible whales (Table 1), were all moving in the same direction, southeastwards along the Yugor Peninsula coast. These belugas were viewed using 31 cm WorldView-3 satellite image and, at this resolution, the overall body shape and flukes could clearly be seen in most whales (see Figure 3a). All whales in groups 1, 2 and 3 were within 500 m of the coast.

Two further groups were also found along the Yugor Peninsula (groups 3 and 4 of area 2). The third group was the largest with 125 visible animals (Table 1); these were located at the mouth of the Kara River flowing off the Yugor Peninsula (65.061°E, 69.272°N). They were orientated in a slightly more random direction, although most (~70%) were pointing southwest towards the river mouth. The fourth group, slightly further to the east, was the smallest with only 16 whales (Table 1). The orientation of these belugas was less homogeneous than the other three groups suggesting that they may have been foraging or milling in this location rather than traveling.

In area 3, the bottom part of Baydaratskaya Inlet, two groups were counted (groups 5 and 6; Figure 2). These groups were viewed in ESRI World Imagery using WorldView-2 imagery at 50 cm. In this imagery, belugas were less distinct than the WorldView-3 imagery used further west, the edges of the whales were less sharp, and the flukes were not visible or difficult to see (see example in Figure 3B).

Group 5 comprised of 73 whales (Table 1), and all were facing southeast, traveling towards the bottom of the inlet. From the ESRI World Imagery we suspected that the entire group had not been captured and it seemed likely that there was an unknown portion of the group off the image further to the west. Fortunately, the image used in ESRI World Imagery was from a stereo pair (an overlapping pair of images taken almost at the same time from slightly different angles) and a second, slightly earlier image, extended further to the west as listed in the Maxar Technologies (formerly DigitalGlobe) archive, which was sourced from DigitalGlobe Foundation. This image taken 73 s earlier revealed a large increase in group 5 from 73 to 213 (group 5a, Table 1). The reason for this increase is due to the fact that the ESRI World Imagery of area 3 did not cover the exact same area as the raw image acquired from Maxar Technologies, with the latter image (ID 103001005 AD12400) expanding 15.8 km further west. In this image the group of belugas (group 5a), which was only partially captured in the ESRI World Imagery compilation (5), was fully covered in the downloaded WorldView-2 image, with 213 whales (5a; Table 1).

Groups 5 and 5a were made of smaller subgroups (all animals within two body-lengths and orientated the same way), which remained relatively similar for the overlap region between the ESRI World Imagery and the raw imagery acquired from Maxar Technologies. This included 19 subgroups that overlapped, in image 5 the total number of

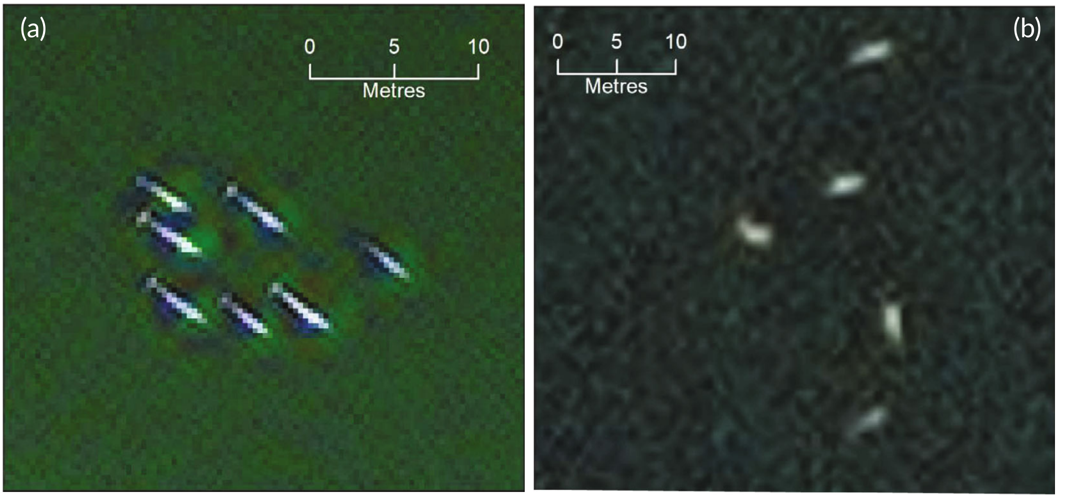

FIGURE 3 The difference of belugas imaged using pansharpened 31 cm WorldView-3 imagery (A) or pansharpened 50 cm WorldView-2 imagery (B). On the left (A), belugas are from area 1 and are all orientated in a similar direction, moving southeast, while the whales on the right (B), from Group 6, area 3 are orientated in a more random fashion suggesting a foraging or milling behavior.

overlapping whales was 71 with a mean subgroup size of 3.7. In image 5a the total number of whales was 64 with an average subgroup size of 3.4. Of the subgroups, 12 of the 19 had the same numbers in both images. Subgroups varied in size between 1 whale and 15. This similarity in subgroup size between images suggested that these were the same whales in each image. It also allowed us to estimate the distance traveled over the period between the two images. On average, the subgroup pods of whales that were in both images had moved in the same direction approximately 311 m (*SD* 39.6, range 214–362 m) in the 73 s between images (~15 km/hr). We estimated the movement of the subgroups based on numbers in each subgroup, which, as they were moving, tended to remain the same or similar, measuring from the center of each subgroup. Interestingly most subgroups moved a similar distance and direction in the intervening 73 s.

In the central portion of Baydaratskaya Inlet, we counted 716 whales in the ESRI World Imagery (group 6; Table 1). In the raw image acquired from Maxar Technologies and captured 73 s earlier, there were 721 whales (group 6a; Table 1). The belugas in groups 6 and 6a had random orientations and we assume from this that they were foraging or, possibly, milling. These random patterns and lack of subgroups made it more difficult to assess whether the same whales were on the surface, and it may be that more whales may have been submerged than in the groups 1–5. It is also possible that diving whales come in and out of view between the two images, although interestingly the overall number of animals was very similar.

3.2 | ESRI World Imagery versus raw images

The ESRI World Imagery is a single flat layer and as such, contrast of individual images cannot be adjusted. To test whether it would be beneficial to change the image settings, and whether this would reveal more whales or make counting easier, the individual WorldView-3 image of area 1 (whale groups 1 and 2) was acquired. Tests showed that although the contrast levels and image stretch type could be improved by using the locally downloaded image (a feature that is not possible on the online version ESRI World Imagery layer) no more whales were visible in the raw image than could be seen on the online version.

3.3 | Conversion of surface whales to aggregation estimate

For the total count, we included the counts from groups 1–4, 5a, and 6a, which comprised 1,147 whales. These results only refer to whales seen on the surface and do not take account of availability bias. From the total count of surface whales, we provide a minimum abundance estimate for the aggregation in the areas surveyed based on known availability bias as defined in the methodology is. Applying the correction values of the previous aerial surveys (40%–55% visibility from Boyd et al., 2019; Kingsley & Gauthier, 2002; Richard et al., 1994; as per Methods section), would give us an estimate of between 2,164 and 2,867 belugas, respectively. However, as we see from the overlapping imagery that most of the animals in transit are visible most of the time, it seems appropriate to use the Matthews et al. (2017) availability estimate on these belugas. This will give a total of 1,750–2,427 whales (410 at 70%–100% and 737 whales at 40%–55%).

4 | DISCUSSION

The results show that belugas at the surface are identifiable and can be counted in both 50 cm and 31 cm imagery. In the higher resolution imagery, the presence of flukes and the shape and size of the objects would suggest that whale identifications are definite (as per the classification system of Cubaynes et al., 2019). In the coarser 50 cm imagery, the shape of the whales is less distinct and one could imagine a scenario where single animals could be mistaken for white caps in rougher sea conditions, making identification less definite. In 50 cm imagery, it could be possible to mistake single beluga for walrus, or groups for narwhal However, there are no confirmed walrus haul outs within 500 km and no suggestion of narwhal in the region, although it is impossible to have absolute certainty that all pods were beluga whales when using satellite imagery (Charry et al., 2021).

Satellite imagery can cover much larger areas than aerial survey; a recent fin whale survey by VHR imagery in the Pelagos Sanctuary covered 32,600 km^2 (Tethys Research Institute, 2020), a similar area to the whole of the southern Kara Sea. Therefore, it may be possible to image entire target areas, rather than estimate abundance from a limited number of line transects typical of aerial surveys. Indeed, by using the ESRI World compilation, it is possible to assess large areas online at no cost. However, this single layer of VHR satellite imagery contains imagery from all times of year and if, as with many organisms including beluga whales, the target species is only present for a limited time each year, only a minority of the satellite compilation will be suitable.

The results of this study raise a number of questions for further research:

- Firstly, although the southern part of Baydaratskaya Inlet was fully covered by imagery, only a small proportion (107 km or approximately 15% out of the 715 km length) of the eastern coast of the Yugor Peninsula had suitable imagery in the ESRI World Imagery viewer. This part of the coastline, covered by imagery, contained 213 visible whales, and it is impossible to extrapolate this number to the entire coast, therefore our counts and estimates should be considered a minimum conservative estimate of a larger population.
- The second consideration is that the images of areas 1 and 2 were taken 5 days before the image of area 3, and some, of the belugas in the first two images were in transit towards area 3 (particularly the 72 whales from groups 1 and 2). It is quite possible that some of the 213 whales (groups 1–4) counted in the images taken on the July 4 had reached area 3 by the time that the image of that area was taken (July 9), and therefore could have been counted twice. If the belugas in only area 3 are considered, it would give an estimate of 1,340–1,842. However, as the 141 visible belugas in area 2 were not in transit, but milling near the outflow of the Kara River, it may be that this area is also an important foraging ground. Whether there were more belugas migrating along the coast at the time that the image of area 3 was taken is unknown.

It is possible that in the past Baydaratskaya Inlet used to be occupied by a separate summer breeding population, which suffered a dramatic decline following harvest in 1950–1960s. In recent decades, belugas have been occasionally observed in the inlet (e.g., Bondarev & Prischemikhin, 2001), suggesting the stock has reoccupied Baydaratskaya Inlet. This present count of over 1,000 (and possibly over 2,000) belugas is by far the largest estimate known to us of beluga whales in this area. It is important to monitor the use of the inlet by belugas especially given that this region is heavily exploited by hydrocarbon industry. Satellite imagery is a cost- and time-effective means (much of the imagery was freely available and the counting of whales took two days), which we would recommend for preliminary study and planning of future beluga research effort in the region.

This study highlights the aggregation of beluga whales in the area and points to the need for further survey to assess the recovery over the whole area, including the Kara Sea and possible migration routes and linkages to population in Nova Zelemya. The population was heavily harvested in the 20th Century, but the evidence here suggests that there is now an important regional aggregation of whales in this area. It is not yet possible to say whether the population is fully recovered, as it is difficult to assess from catch records what the historical original population was and this study is only a partial survey of the whole area.

4.1 | Conclusion

Overall, this study confirms that VHR satellite imagery is a powerful tool for assessing beluga populations and movements. Although freely available VHR satellite image compilations such as ESRI World Imagery can be useful for preliminary study, much of the imagery will be unsuitable, and the separate multiband satellite images should be acquired where the user has control over parameters such as timing weather and sea conditions. Here we confirm the presence and provide a preliminary abundance estimate of an unstudied summer aggregation (possibly, a stock) of beluga whales in Baydaratskaya Inlet.

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AUTHOR CONTRIBUTIONS

Peter T. Fretwell: Conceptualization; data curation; formal analysis; investigation; methodology; resources; validation; writing – original draft; writing – review and editing. **Hannah C. Cubaynes:** Conceptualization; methodology; writing – review and editing. **Olga V. Shpak:** Validation; writing – review and editing.

ORCID

Peter T. Fretwell https://orcid.org/0000-0002-1988-5844

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