Observations of cetaceans in the waters of the Surtsey Nature Reserve between 2008 and 2021

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ABSTRACT

The island of Surtsey originated from an underwater eruption in 1963 and has since been studied extensively, illustrating the colonization and succession by numerous species in both the terrestrial and marine habitats. However, there is little information on the cetaceans occurring near the island. Here we show that killer whales, pilot whales and minke whales are observed within the Surtsey Nature Reserve in June-August, although survey effort within this area has been lower than in other parts of the Vestmannaeyjar archipelago. Thus, we expect the list of species will increase with higher effort in the future. Killer whales were the species observed most commonly and were seen during the summer months, most often on the east and north coasts. Both observational and animal-attached tag data suggest killer whales were feeding within the reserve, and the only prey identified was herring. However, seasonal survey effort limits a comprehensive understanding of the prey killer whales may target within this area and particularly whether killer whales may target the seal colonies established here during autumn and winter. In the future, increased effort in summer and at other times of the year, would help fill in these gaps in our knowledge of the importance of the Surtsey nature reserve for cetaceans.

INTRODUCTION

Iceland sits at the confluence of warm and cold Atlantic water masses which contribute to the high productivity that creates a rich environment for top predators, such as cetaceans (Víkingsson *et al.* 2015). The occurrence of several species of cetaceans in coastal waters has led to the development of whale-watching in towns along the southwest, west and north coasts of Iceland (Rasmussen 2014). The waters off the south coast of Iceland are productive, rich in marine life, and have unique physical oceanographic characteristics with diverse marine habitats, such as areas of shallow and deep waters off the shelf (Astthorsson *et al*. 2007). It is, thus, a region expected to be suitable habitat for cetacean species. However, the occurrence of cetaceans along the south coast of Iceland is little monitored due to the lack of dedicated research effort or whale-watching activities.

The Icelandic Orca Project was initiated in the Vestmannaeyjar archipelago in 2008, becoming the longest-running dedicated research and monitoring programme of killer whales (*Orcinus orca*) in Icelandic waters (Samarra *et al*. 2017a). Killer

whales are known to occur in the archipelago in the summer months to feed on the herring that spawns locally in July (Óskarsson & Taggart 2009). While the project had an initial focus on killer whales, it also collects information on other species sighted within the archipelago to record the cetacean biodiversity of the region. Several species of cetaceans have been recorded in this region, however their use of different areas of the archipelago has not been explored to date.

The island of Surtsey, the southernmost island of the Vestmannaeyjar archipelago and Iceland's southernmost outpost, was formed as a result of an oceanic eruption that occurred between 1963 and 1967. The island has been legally protected from its birth, creating a pristine natural laboratory where a long-term study of biological colonisation and succession has been established. To date, hundreds of species have been described on the island including moulds, bacteria, lichens, fungi, plants, invertebrates, breeding seabirds and seals (Magnússon *et al*. 2020). In the marine environment, several benthic marine algae, invertebrates, and fish species have also been reported (e.g., Jónsson & Gunnarsson 2000; Hauksson 1992, 2000; Baldursson & Ingadóttir 2007). The island is continuously changing as erosion leads to recession of the coastline, which is predicted to continue for at least another century (Jakobsson *et al*. 2000). Thus, the current composition of the benthic and pelagic communities will likely change in the future as the habitat matures into a more stable stage (Gunnarsson & Hauksson 2009). The island and surrounding marine area were inscribed to the World Heritage List of UNESCO in 2008 (Baldursson & Ingadóttir 2007). Here, we aim to report on observations of cetaceans sighted within the Surtsey Nature Reserve (SNR), to complement other studies that have documented the presence of different marine and terrestrial species present in this habitat.

MATERIAL AND METHODS

Whenever weather conditions permitted, small research vessels were used to search for whales in Vestmannaeyjar. The boat(s) departed from the harbour of Heimaey and effort was generally concentrated in the west and central part of the Vestmannaeyjar archipelago. Searches were conducted in an area bordered to the west by Þrídrangar and to the south by Surtsey. In some years, the search by boat was aided by observers based on land, that also searched for whales within the same study area and directed the boat to whale sightings. The focus of the fieldwork was on killer whales but as much as possible other species sighted were also recorded.

Between 2008 and 2016, fieldwork was only conducted in the month of July; from 2017 to 2021, fieldwork was conducted in June, July and August, although the effort in 2020 was constrained by the COVID-19 pandemic. Effort varied primarily due to weather and research priorities. Boat tracks during surveys were saved to collect information on survey effort and areas searched, although this was not conducted as consistently in 2008 and 2010 as it was in all other years. Despite varying research priorities from year to year, photographs of whales were collected every year for identification purposes. Photo-identification is a technique which uses unique markings on the bodies of individuals to identify them, making it possible to collect information at the individual level. In the case of killer whales, individuals were identified based on the size and shape of the dorsal fin, the presence of nicks and scars, saddle patch (the lightly coloured area below and behind the dorsal fin) pattern and body scars (Bigg et al. 1990). Photographs were collected continuously during boat surveys in an attempt to identify all the individuals present within an encounter. Photographs were collected using a variety of digital single-lens reflex cameras and lenses. Photographic cameras were synchronised with GPS time on a regular basis so that the location where pictures were collected could be determined. In recent years, cameras with integrated GPS sensors were used that recorded the GPS coordinates directly to the picture metadata.

To investigate the effort conducted within the SNR, boat tracks from every field season were plotted on a map to illustrate the proportion of the effort that occurred within this area. The SNR investigated here included the boundaries of the area nominated for the World Heritage List of UNESCO as well as a surrounding buffer zone, as determined in the nomination of Surtsey for the UNESCO World Heritage List document (Baldursson & Ingadóttir 2007). Maps were generated using QGIS v3.8 (QGIS.org 2022) and using data on land limits from the IS 50 V database of the National Land Survey of Iceland (2022). The locations of collection of pictures of different whale species were used to characterise the species observed within the nature reserve, as well as where these species were seen.

In 2009, killer whales were tagged with digital archival tags (Type B Suction-cup attached tag that includes DSL400-VDT II and PD3GT19, Little Leonardo, Aoki *et al.* 2012, Miller *et al*. 2016, and Dtags, Samarra & Miller 2015) attached to the whales with suction-cups using a 7 m carbon fibre pole from a small zodiac (<6 m length). The tags emitted a VHF signal that allowed the tagged whale to be tracked after deployment. The tagged whales were followed generally at distances of more than 100 m, from the tagging boat or from a 9.45 m observation motorboat, using the VHF signal and visual observations. The different types of tags included a different suite of sensors but all had a pressure sensor (sampling rate 1 Hz for Little Leonardo tags and 50 Hz for Dtags), which allowed for the diving behaviour of the tagged whale to be investigated. An animal-borne camera DSL400-VDT II (Little Leonardo) collected one still image every 4s.

RESULTS

Surveys around Vestmannaeyjar were conducted on a total of 213 days between 2008 and 2021, covering a distance of 17247 km. Approximately 3.3 % of this effort, or 572 km, were inside the SNR (Table 1). While all years, except 2010, had some effort inside the SNR, the amount of effort varied considerably between years.

Killer whales were sighted inside the reserve in 7 out of 11 summer seasons when there was effort in this area. A single minke whale (*Balaenoptera acutorostrata*) was also reported in the reserve in 2009 as was a group of long-finned pilot whales (*Globicephala melas*) in 2019. Across all years, killer whales were observed in June (n = 1), July (n = 7) and August (n = 4). Greater sightings in July reflect the effort occurring mostly in July in the earlier years of the project. Killer whales seem to have been observed most often on the east compared to the west coast

Table 1. Cetacean survey effort in the Vestmannaeyjar archipelago and within the Surtsey Nature Reserve (SNR) in 2008–2021. The maximum number of boats refers to the maximum number used within a given year but not all boats were used every day.

Year	Month	Total effort (days)	Effort inside SNR (days)	Total distance (km)	Distance inside SNR (km)	Max. number of boats	Species sighted inside SNR (n days)
2008	July	7	2	131.67	23.10	1	Killer whale (2)
2009	July	19	3	2474.86	324.68	3	Killer whale (1), minke whale (1)
2010	July	6	NA	NA	NA	2	-
2013	July	11	1	1090.16	24.88	2	-
2014	July	16	2	973.00	14.97	2	-
2015	July	20	1	1678.56	18.06	2	Killer whale (1)
2016	July	15	3	914.53	4.56	1	Killer whale (1)
2017	June	9	-	809.65	-	1	-
	July	12	-	727.42	-	1	-
	August	6	1	431.31	15.72	1	-
2018	June	4	-	223.20	-	1	-
	July	13	1	981.90	12.93	2	-
	August	7	3	631.72	40.88	1	Killer whale (3)
2019	June	9	1	727.78	2.23	1	Killer whale (1)
	July	11	1	867.55	3.46	2	-
	August	6	3	393.56	30.13	1	Pilot whale (1)
2020	July	9	1	518.53	0.37	1	-
	August	3	-	227.00	-	1	-
2021	June	8	-	566.88	1.15	1	-
	July	15	3	2228.68	39.84	2	-
	August	7	1	649.03	15.35	1	Killer whale (1)
Total		213		17246.99	572.31		

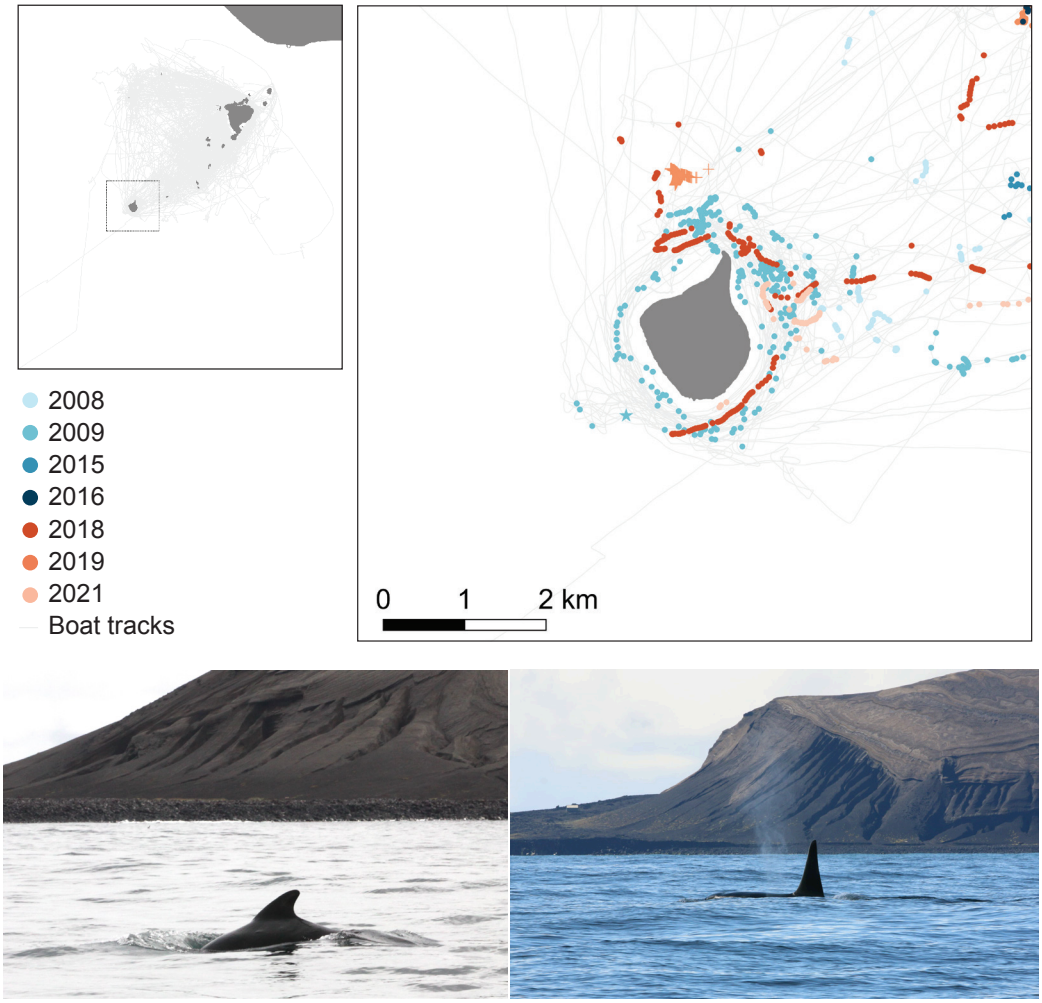

Figure 1. Map of Vestmannaeyjar displaying in light grey all boat tracks to illustrate the spatial distribution of effort (top left). Insert of the Surtsey Nature Reserve showing boat tracks within the reserve and locations where photographs of killer whales (•) and pilot whales (+) were collected between 2008–2021 (top right). A minke whale was observed from the research boat once (star) but no photographs were collected. A single pilot whale (bottom left) and a single killer whale (bottom right) can be seen within the Surtsey nature reserve.

of Surtsey (Fig. 1). Killer whale behaviour was not consistently sampled across the study period, except between 2016 and 2021. In these years, killer whales were observed feeding on herring in the waters around Surtsey in 2 out of 6 encounters. In other encounters, killer whales were observed travelling, with some instances of milling behaviour (travelling in circles, surfacing in different directions and lack of consistent directional movement).

On the 25th July 2009, a female killer whale was tagged at 12:22 inside the SNR. The tag recorded the whale's underwater behaviour for approximately 10h, during which the whale was continuously inside the SNR, thus providing an interesting case study for the use of this habitat by killer whales.

The tagged whale was female IS063, part of a group that is seen regularly in the waters of Vestmannaeyjar during the summer months (Fig. 2 top center). The female was accompanied by the remaining members of the group (cluster G, Tavares et al. 2017). During >10hr of observation, the whale and its group circled the island of Surtsey at least 5 times (Fig. 2 top left). Visual observers on board the research boats recorded occasional notes of the whales' behaviour as well as information from the vessel's echosounder display, as an indication of the potential presence of fish in the area. The echosounder was not on for the first 1.5 hrs of the deployment and it was intermittently off during the deployment when acoustic recordings were attempted. Between 18:36 and 19:35, the observers reported fish observed on the echosounder. However, the whale's diving behaviour

during this period was not apparently different from other periods of time in the deployment, consisting of both shallow and deep dives but to similar depths as throughout the remainder of the deployment duration (Fig. 2 centre panel). The main difference is that around 19:00 the whale began a longer period of deeper dives (approx. 2.5hrs) than observed at any other point in the deployment (generally <1h), which could be indicative of feeding behaviour. The tag stopped recording at 22:44 due to a full memory but did not detach from the whale until the following day. Because the tag was still attached to the whale, the observational boat continued tracking the whales after sunset but had to leave the area soon after because it became too difficult to continue sighting the whales in low light. At this point, the whales appeared to be leaving the area, towards the southwest.

An analysis of the pictures collected by the tag could not confirm the presence of prey, due to low underwater visibility, which is characteristic of this

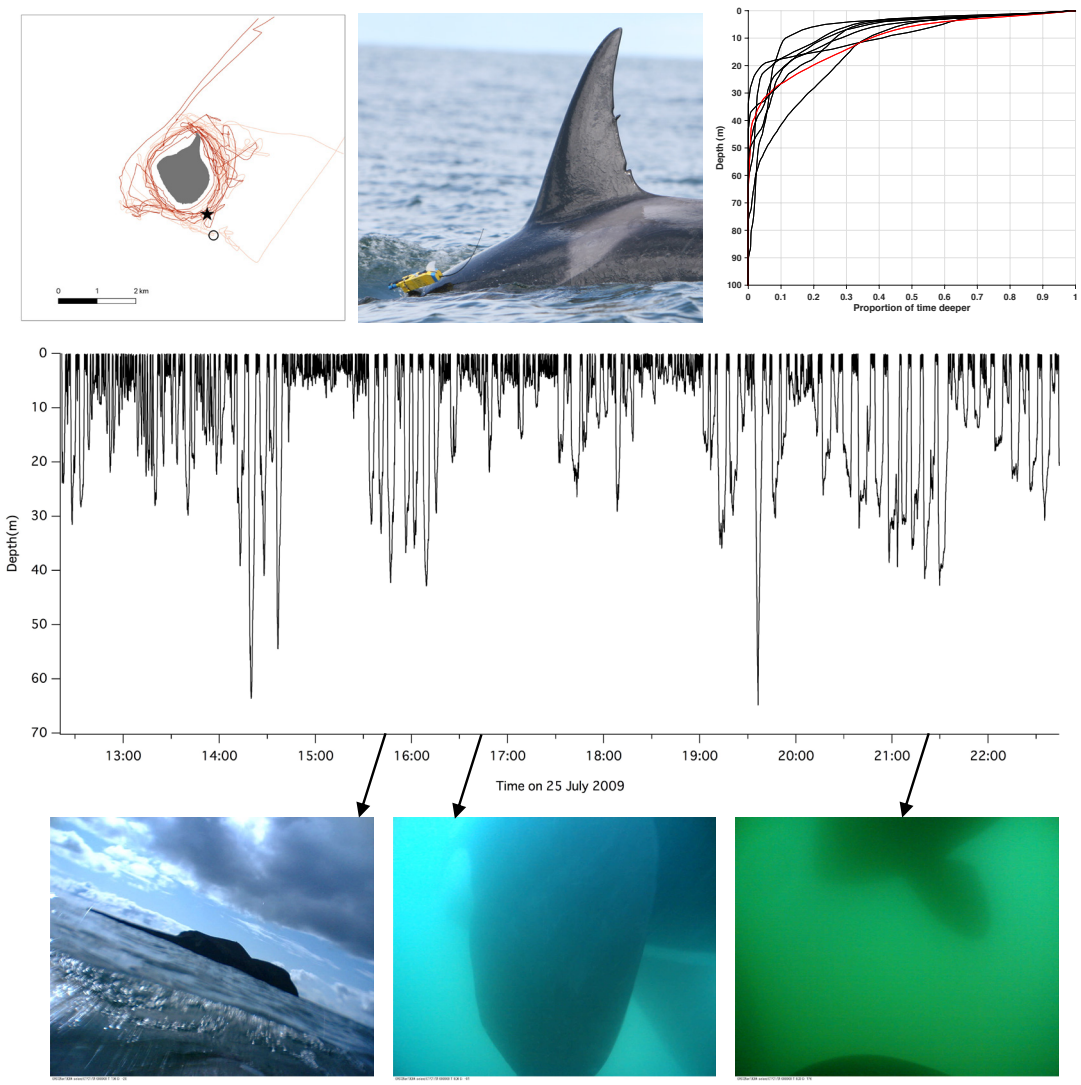

Figure 2. Top panel: left) map illustrating the boat tracks of the two research vessels on 25 July 2009 while searching, tagging and then tracking tagged whale IS063 (at a distance of >100 m) as a proxy for the movements of the tagged whale and its group; centre) photograph of IS063 carrying the tag; right) cumulative depth use of tagged whale IS063 (red) compared to another 7 whales tagged during the same field season (black). Note that the location where the tag was deployed (star) and the location where the tag stopped recording (circle) are marked on the map on the top left. The observation boat (orange line) followed the whales to the southwest until the light was too low to continue, at which point the boat made a sharp turn towards the northeast to leave the area. Centre panel: Dive profile of whale IS063 for the entire duration of the tag deployment. Bottom panel: Example photographs captured by the tag attached to whale IS063, showing the island of Surtsey during a moment when the whale surfaced to breathe, and the proximity of other members of the group to whale IS063 while swimming underwater, illustrating poor underwater visibility. The black arrows show when during the tag deployment the photographs were captured.

area, as a result of the outflow of large glacial rivers along the south coast of Iceland. Yet, the use of the water column exhibited by the whale throughout the deployment was similar to that observed in other whales tagged in the wider Vestmannaeyjar region in 2009, as illustrated in Fig. 2 (top right) by the cumulative depth use (as in Miller *et al*. 2010). Some of these whales were confirmed to be feeding by inspection of acoustic data recorded on some of the tags, or by visual observations. This suggests that whale IS063 and her group might have been feeding in the area around Surtsey during the tag deployment, even though that was not clearly obvious from surface observations. Indeed, the whales were not observed clearly milling with seabirds present flying above the whales in circles or plunge-diving into the water to feed on fish gathered by the whales – both common indications of herring feeding behaviour. Nevertheless, the circling behaviour observed may have been foraging effort, searching for prey within this environment.

DISCUSSION

This study illustrates the common occurrence of cetaceans in the waters around Surtsey. It confirms the presence of killer whales and minke whales, which had also been reported by Baldursson & Ingadóttir (2007) along with harbour porpoises, and adds pilot whales to the list of species observed in the SNR. It was particularly killer whales that were observed more regularly, with minke whales and pilot whales sighted only on one occasion each. However, the effort surveying the waters around Surtsey was very limited compared to the rest of the Vestmannaeyjar archipelago (Table 1), which limits our ability to detect different species occurring in this area. The boat effort was reduced and, in general, the waters around Surtsey were only surveyed if whales were not encountered in other parts of the Vestmannaeyjar archipelago closer to Heimaey or if observers on land directed the boat to whales sighted around Surtsey. Land observations were most commonly done from Stórhöfði, in the southern tip of Heimaey, approximately 20 km away from Surtsey. Even though the observers had binoculars with large magnification (15x), detecting whale presence around Surtsey was only possible during very good weather conditions. Thus, we expect that the list of species may increase in the future, and the patterns of which species more frequently occur in the SNR may also change with additional survey effort.

Killer whales were observed most often on the east and north compared to the south and west coasts of Surtsey. Though that could have been due to greater survey effort in those areas (Figure 1), the east coast of Surtsey is a more stable and sheltered area that has suffered less erosion from wave action than elsewhere on the island, which can be explained by the prevailing southwesterly winds in this region (Jakobsson *et al*. 2000). That has resulted, for example, in an increased diversity in algal cover (Jónsson & Gunnarsson 2000; Gunnarsson & Hauksson 2009) and a somewhat higher number of benthic species (Hauksson 2000). Thus, this could be habitat more suitable for killer whale prey, compared to elsewhere around the island, which could explain the apparently higher killer whale presence.

Killer whales were seen in every month of the summer (June to August), but most often in July. This reflects the study effort but also coincides with the expected period of higher abundance of spawning herring in the Vestmannaeyjar archipelago (Óskarsson & Taggart 2009). Both observational and tag data suggest that killer whales feed within the SNR, and that they are feeding on herring, similar to what is observed in the wider Vestmannaeyjar archipelago in the summer months (Samarra *et al*. 2017a, b). Herring distribution patterns around the Vestmannaeyjar archipelago during the spawning period have, to our knowledge, not been studied and thus there is little understanding of how often herring use the SNR and when in the season that happens. Nevertheless, the observations of herring predation by killer whales within the SNR reported in this study suggest at least part of the herring stock uses this area during the spawning season. Future studies that aim at quantifying the spatial distribution of herring within Vestmannaeyjar and how that may change throughout the summer should help determine the importance of the SNR for herring and, consequently, herring predators such as the killer whale.

It has been proposed that the presence of seals has attracted killer whales to the area of Surtsey. Both harbour seals (*Phoca vitulina*) and grey seals (*Halichoerus grypus*) are seen in Surtsey at different times of the year (Hauksson 1992, 2009, 2015). Harbour seals appear to haul-out in great numbers in the winter-time on the northern shore of the island during feeding, but are not numerous during breeding time in summer (Hauksson 2009). Grey seals appear

to make extensive use of the island as a breeding colony in October-November, and in fact in 2017 the breeding colony of Surtsey was the largest of all the colonies located in the south coast of Iceland, with an estimated pup production of 134 (Granquist & Hauksson 2019). Killer whales are known to predate on both seal species in Iceland (Samarra *et al*. 2018), and the analysis of dietary markers of some individual whales sighted in Vestmannaeyjar indicates that they have a mixed diet, including both fish and marine mammals (Samarra *et al*. 2017b). Thus, it is possible that killer whales predate upon seals in Surtsey. However, to date no observations of predation on seals have not been reported in the SNR, or in the Vestmannaeyjar archipelago as a whole. The lack of effort to visually monitor the presence of killer whales, or other cetacean species, in the SNR in any season outside of summer clearly limits any conclusions on potential seal predation, as seals appear to be using the area more intensively during autumn and winter.

Future observations of cetacean occurrence in Surtsey and its surrounding waters could reveal a broader range of species using this area as well as a larger range of prey being consumed by killer whales than what has been documented to date. Increased dedicated research in the SNR would be beneficial to understand how the various species of cetaceans occurring in the Vestmannaeyjar archipelago use this habitat. This could be achieved, for example, using passive acoustic monitoring techniques, that can be used year-round independent of weather conditions, or with increased effort on dedicated visual research at least during summer. Increased monitoring would also allow for a better understanding of how species occurrence and habitat use may change in the future as the island continues its recession.

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