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Brief Report

A First Study on Distribution Characteristics of Common Dolphin in Korean Waters: A Study Using Data Collected during the Past 20 Years

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Abstract: The common dolphin (*Delphinus delphis*) is the second-most bycaught species in Korean waters. To provide key information about their habitat boundaries and hotspots for spatial conservation and management, the spatial use of this species was examined using data obtained from sighting and bycatch surveys of cetaceans in the past 20 years. The 95% minimum convex polygon and 95% density contour of fixed-kernel analysis suggested that the boundary of the home range of common dolphins is limited to the coastal region (Busan–Sokcho) of the East Sea/Sea of Japan. From 50% density contours drawn by kernel density estimation, it was suggested that their hotspots are around the coast of Ulsan–Pohang, Doghae, and Sokcho within the home range. Common dolphins were not observed in the Yellow Sea. Hence, shallow waters in the geographic area of the coastal region of the Yellow Sea are likely not a suitable habitat for common dolphins in this region.

Keywords: hotspots; minimum convex polygon; kernel density estimation; common dolphin; Korean waters

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1. Introduction

Fisheries bycatch is currently the largest source of human-caused deaths of marine mammals worldwide [1]. To reduce the global bycatch of marine mammals, international protection policies have been implemented [1,2]. In Europe, all cetaceans are strictly protected under the articles of the EU Habitats Directive [2]. The United States enacted regulations under the Marine Mammal Protection Act aimed at reducing marine mammal bycatch in international fisheries in 2016 [1]. These regulations require any country exporting fish and fish products to the United States to have or establish marine mammal protections equivalent to those in the United States [1].

In many countries, spatial conservation or protection initiatives, which focus on the protection of key areas and habitats, have attempted to reduce marine mammal bycatch [3–5]. According to Slooten, 2013 [4], to stem the decline of the Hector's dolphin population resulting from fisheries mortality in New Zealand waters, marine protected areas (MPAs) have been continually extended since 1970. As a result of the extension of MPAs, the decline in New Zealand's dolphin populations slowed or halted in 2008 [4]. Tomás and Sanabria, 2022 [6], introduced the histories and areas of MPAs in the Wadden Sea along the coasts of Denmark, Germany, and The Netherlands; the Banks Peninsula, located on the east coast of the South Island of New Zealand; the Humpback Whale National Marine Sanctuary, located in Hawaii; and Melville Bay in Greenland, suggesting the effectiveness of spatial protection measures for marine mammals. Therefore, understanding the distribution or geographical range of a species is a key factor to prioritize spatial management for species conservation [7].

Home range analyses are a common method used to determine the distribution of marine mammals [8]. According to Burt, 1943 [9], the home range of an animal is defined as "that area traversed by an individual in its normal activities of food gathering, mating, and caring for young". Typically, the home range reflects habitat use [10]. Marine mammal populations often have hotspots [9], which are often termed small geographic areas with a high density of animals [4,11].

The common dolphin (*Delphinus delphis*) is a globally abundant species that is mainly distributed in the tropical and temperate waters of the Atlantic and Pacific oceans [12,13]. In addition, several studies have found common dolphins in coastal regions [14–16]. In Korean waters, the common dolphin is the second-most bycaught species [17]. It is mostly observed and bycaught in the coastal regions of the East Sea [18–20]. Lee et al., 2018 [17] reported that over 250 common dolphins per year were bycaught by commercial fisheries in the East Sea from 2011 to 2017. The common dolphin bycatch in Korean waters was mainly found in set and gill nets [18]. In Korean waters, both set and gill nets are widely used. Set nets are stationary fishing nets, while gill nets are mostly classified into stationary and mobile fishing nets in Korean waters. Although set nets are fixed at a certain position legally permitted in the coastal region, gill nets are operated anywhere in coastal and offshore regions in Korean waters. Therefore, it is necessary to develop appropriate spatial management initiatives to reduce common dolphin bycatch. However, there is little information on their spatial characteristics; focusing on key areas and habitats of the common dolphin is necessary to make spatial management decisions.

In Korean waters, cetacean hunting continued until 1986 when the killing of cetaceans stopped as a result of an IWC moratorium on commercial whaling. Then, cetacean research began with sighting surveys in 2000 and was continually conducted until the present [20]. Since a legal system for collecting information on cetacean bycatch was established in 2011, the spatial and temporal information on cetacean bycatch has improved [18].

In this study, two simple questions were considered: where do common dolphins live in Korean waters, and where do hotspots of common dolphins exist in Korean waters? The area used by common dolphins and the existence of their hotspot were examined on the basis of sighting and bycatch surveys of cetaceans over the past 20 years. The present study is the first to describe the spatial use of common dolphins in Korean waters. Our results may provide key information about their hotspots and habitat boundaries for the spatial conservation and management of this species in Korean waters.

2. Materials and Methods

2.1. Sightings Data

Sighting surveys have been conducted primarily to estimate the abundance and determine the distribution of cetaceans living in Korean waters using several research vessels of the National Institute of Fisheries Science since 1999 (Figure 1). The sighting surveys from 2000 to 2020 are summarized in Table 1. Visual line-transect surveys covered 40,543 nautical miles during the study period. The surveys were prioritized in the Yellow Sea (YS) and the East Sea/Sea of Japan (ES) because of the absence of dedicated research vessels and inadequate budges (Table 1). Surveys in subtidal zones about 10 m in depth were not conducted in the YS. The surveys were also carried out in sea conditions of Beaufort $\leq$ 4 and in the closing mode for species identification and group size (number of individuals) estimation by a trained and experienced observer team (4–8 persons) onboard the research vessel. The observers mainly conducted their visual sighting surveys with the naked eye and telescopes. Observers rotated their positions. Left-side observers surveyed from left 60° to right 20°, and right-side observers searched from right 60° to left 20°. An observer who recognized cetaceans set the foremast to 0° to determine the angle and distance between the cetaceans. Zigzag transect lines with a random start were employed within the study area [21]. The visual observations were conducted during the daytime from sunrise to sunset. The speed of the research vessel was maintained at 10–12 knots.

Table 1. Summary of sighting surveys conducted in Korean waters from 2000 to 2020.

Year	Yellow Sea		East Sea		South Sea	
	Survey Dates	Survey Effort (n.miles)	Survey Dates	Survey Effort (n.miles)	Survey Dates	Survey Effort (n.miles)
2000	11 May–1 Jun., 20 Sep.–6 Oct.	1494				
2001	20 Apr.–13 May, 8–24 Sep.	1428				
2002	28 Aug.–15 Sep.	813	19 May–7 Jun.	1169		
2003			21 Apr.–18 May, 17–30 Sep.	1660		
2004	25 Apr.–31 May	1787	31 Mar.–1 Apr., 19–21 Jul., 19–22 Oct.	262		
2005			6–8 Apr., 26 Apr.–25 May, 19–22 Jul., 31 Aug.–2 Sep., 25–27 Oct.	1885		
2006			1 Apr., 25 Apr.–17 May, 25–28 Jul., 20 Sep., 30 Oct.–3 Nov.	1587		
2007	20–23 Mar.	258	5–10 Apr., 25 Apr.–27 May, 12–20 Jun., 17–25 Oct.	1955		
2008	21–25 Feb., 19 Apr.–22 May, 23–29 Jul.	1912	5–12 Mar., 26 Jun.–1 Jul., 25–27 Aug., 20–28 Oct.	565		
2009			28 Apr.–27 May, 25 Jun.–2 Jul., 22–28 Jul.,	1588	12–18 Jun., 22–30 Nov.	625
2010	5–9 Jul.	279	7 May–9 Jun., 24 Jul.–5 Aug., 22–28 Oct.	1481	19–30 Mar.	383
2011	2–30 May, 5–20 Jul.	1465	18–30 Mar., 19–30 Aug.	703	14–23 Sep., 27 Sep.–3 Oct.	534
2012			7–15 Mar., 29 Apr.–13 May, 20–31 Jul., 16–26 Oct.	2666	23–27 Apr.	283
2013	26 Apr.–15 May	1124	12–24 Mar. 18–28 Jul. 28–30 Oct.	796	18–22 Nov.	380
2014	6–19 Mar., 23 Jun.–5 Jul., 16–27 Jul., 23 Sep.–7 Oct.	2740				
2015			2–12 Mar., 24 Apr.–7 May, 15–21 Jul., 23 Oct.–2 Nov.	1575		
2016	17–28 Mar., 26 Oct.–2 Nov.	617	23 Apr.–14 May	691		
2017	20 Apr.–8 May	1052	1–12 Mar., 12–18 Jul., 26 Oct.–7 Nov.	1108		
2018	7–18 Mar., 22 May–3 Jun., 9–10 Sep., 1–5 Nov.	1486				
2019			28 Feb.–5 Mar., 29 May–13 Jun., 25 Sep.–1 Oct.	1223		
2020			18–31 Mar., 26 Apr.–11 May	969		
Total		16,455		21,883		2205

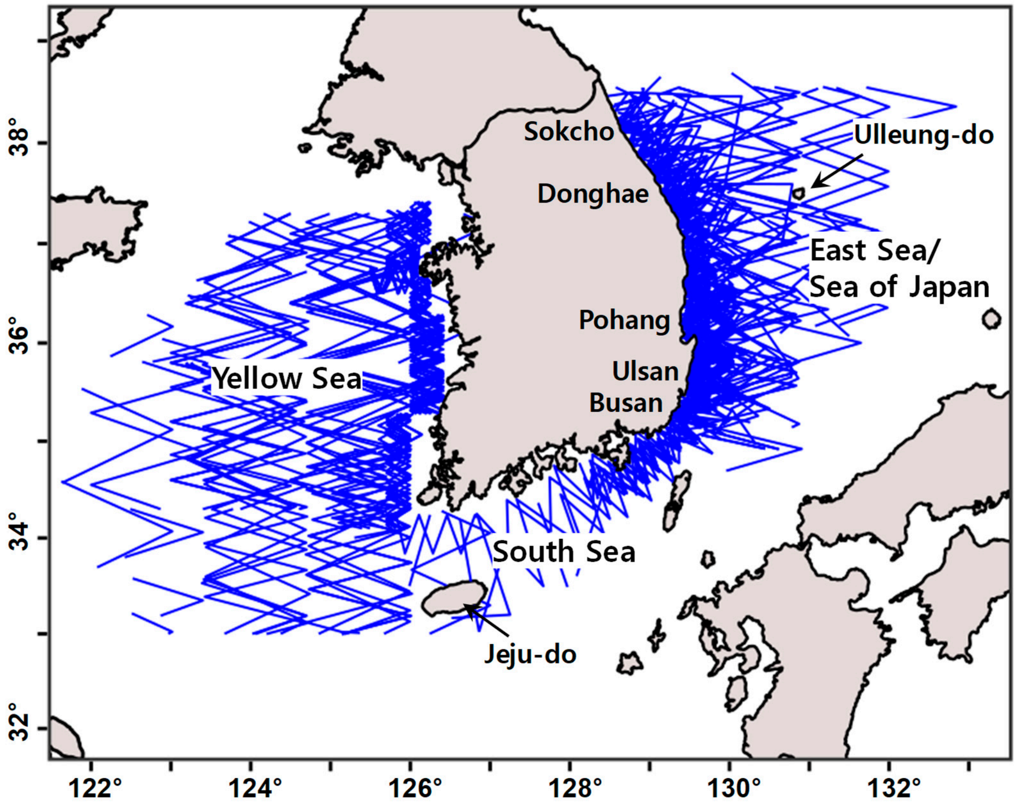

Figure 1. Zigzag transect lines in vessel-based line-transect surveys conducted in Korean waters from 2000 to 2020.

2.2. Bycatch Data

In the Republic of Korea, a certificate for each bycaught cetacean has been issued by the Korean Coast Guard since 2011 [18]. The Korean Coast Guard conducts a mandatory detailed investigation of each bycaught cetacean (bycatch species and position, body injury of the cetacean, etc.) to confirm the case as incidental and report a government-issued certificate in accordance with pertinent laws [18]. In this study, the spatial count data (individuals) of common dolphin bycatch in Korean waters from 2011 to 2020 were obtained from these certificates.

2.3. Data Analyses

The minimum convex polygon (MCP) method and fixed kernel density estimation (KDE) were used to estimate the home ranges [22–25]. The MCP estimator is a straightforward approach that involves creating a convex polygon (i.e., a polygon with no internal angles greater than 180 degrees) encompassing all locational points gathered for an animal or group [24]. The MCP estimation was generally based on all cases collected from the surveys (100% MCP). However, the MCP method has a high sensitivity to outlier locations and tends to overestimate the home range [22,26]. The weaknesses of MCPs can be reduced by applying rules that exclude a certain proportion of the outermost locations (e.g., 95% MCP) [22,27,28]. In the present study, the 95% and 100% MCPs were calculated to find the home range boundaries of the common dolphin in Korean waters using data collected from sighting and bycatch surveys in the past 20 years.

In this study, to determine whether common dolphins used random habitats, the Kolmogorov–Smirnov goodness-of-fit test (K–S test) was applied [29]. The null hypothesis for the K–S test is that the cumulative frequency distribution of the observed data is uniform. Comparison between the observed cumulative distribution and the cumulative distribution expected on the basis of the hypothesized distribution leads to decisions about whether the maximum difference between the two distributions is significant [30]. KDE was used to produce animal density maps by fitting a density function to weighted animal sightings onto a user-defined grid [11]. The function allows users to incorporate a barrier for the interpolation of sightings [11]. Therefore, KDE can account for multiple centers of behavior [22]. Brough et al., 2018 [11], investigated the existence of hotspots of Hector's dolphins in New Zealand with 50% density contours (DCs) extracted from the overall kernel analysis. The 50% DC has been extensively used to define core areas in wildlife distribution studies; it reflects the area in which 50% of the weighted sightings occur [31–33]. In this study, the 50% DC was used as an indicator of the existence of hotspots using data collected from sighting surveys over the past 20 years. The 95% DC for KDE drawn to compare the home range boundaries of common dolphins resulted from the 95% MCP analysis. In the K–S test and KDE analyses, the bycatch data of common dolphins were inappropriate to use without the standardization of bycatch by spatial locations and the efforts of fishing gear. An ad hoc method was applied to calculate a smoothing parameter (bandwidth) for the kernel [34]. All home range analyses were completed using the adehabitatHR package [35] in R (R Development Core Team).

3. Results

Figure 2 shows the locations of common dolphins sighted and bycaught in Korean waters. Common dolphins were mostly found and bycaught in the coastal region of the ES. In particular, there were no findings of common dolphins in the offshore region. In addition, no common dolphins were found or bycaught in the YS. The numbers of common dolphin bycatch events in the ES and South Sea (SS) were 3761 and 8, respectively.

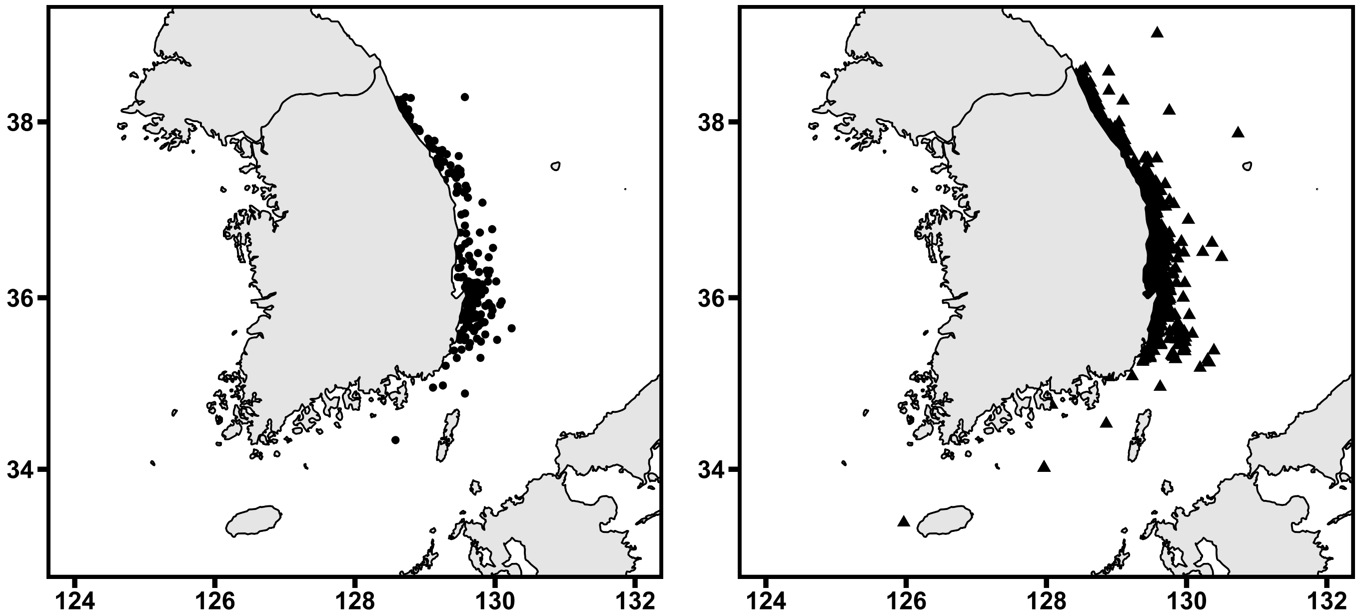

Figure 2. Locations of common dolphins sighted (**left**: circles) and bycaught (**right**: triangles) in Korean waters.

In Korean waters, the polygon area drawn by the 100% MCP was enclosed from the SS to the ES, excluding the YS, while that drawn by the 95% MCP ranged from Ulsan to Sokcho along the coastal region of the ES (Figure 3). The outermost locations of the polygon area for the 100% MCP contained almost all the bycatch locations.

The K–S test results are shown in Figure 4. There were apparent differences in distances between the observed and expected cumulative distributions for sighting locations (both latitude and longitude) of common dolphins. The two distances were significantly different ($p < 0.05$). These results indicate that common dolphins used the coastal region of the ES unevenly.

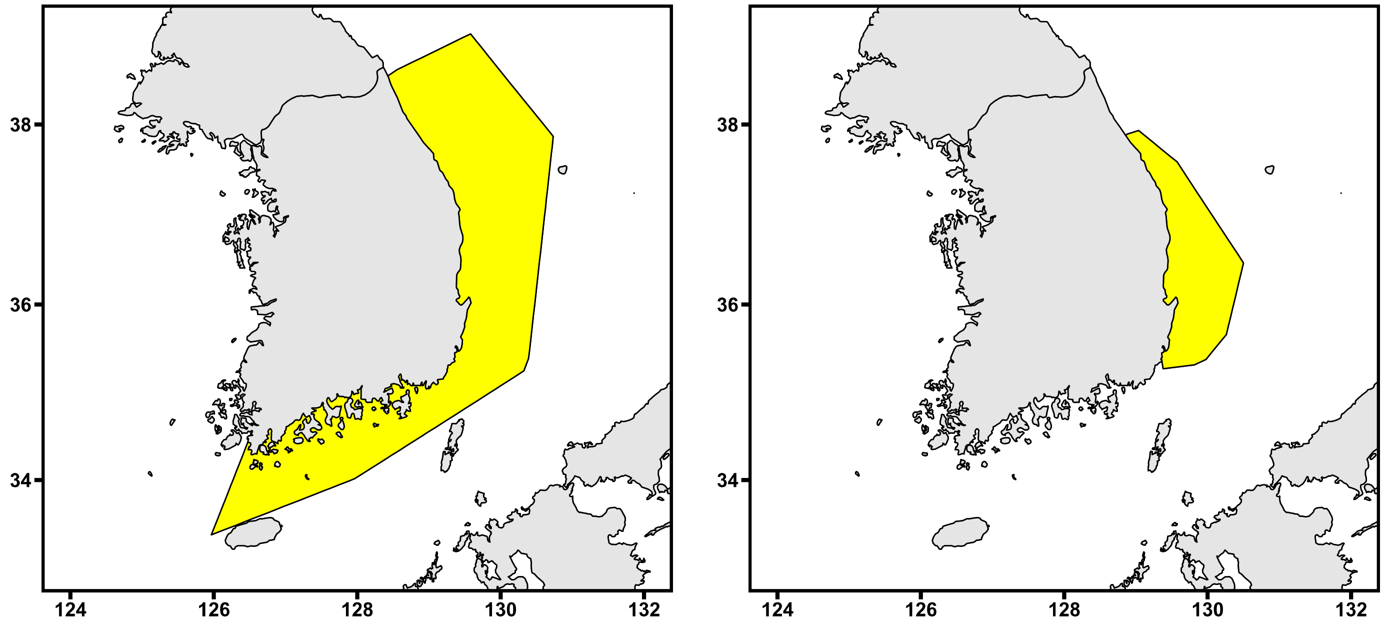

Figure 3. Polygon areas (yellow) enclosed by outmost locations for 100% (**left**) and 95% (**right**) MCPs. Circles and triangles indicate the locations of common dolphins sighted and bycaught, respectively, in Korean waters.

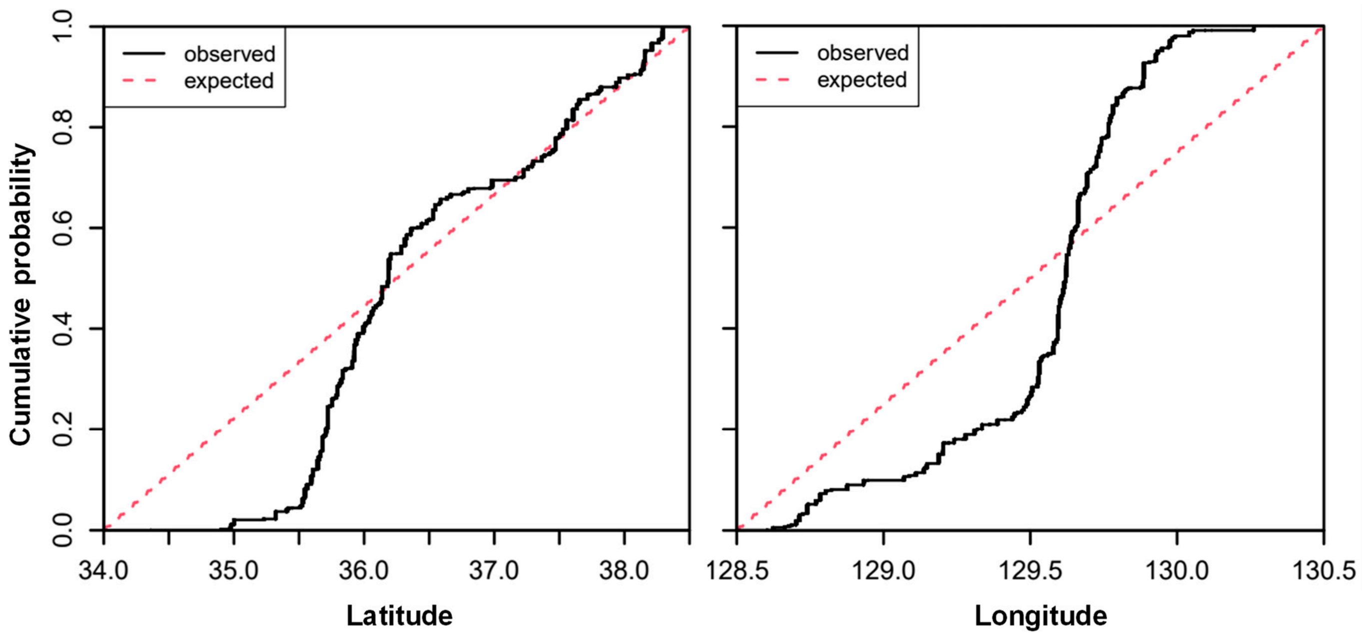

Figure 4. Comparisons of distances between observed (solid line) and expected (dotted line) distributions for K–S test using the location data (longitude and latitude) of common dolphins sighted in Korean waters.

Figure 5 shows the 95% and 50% DCs drawn using KDE analysis. The range of the 95% DC was slightly more extended toward the northern and southern directions than the range of the 95% MCP. In the 95% DC, a large school of common dolphins was observed in a location away from the coast of Sokcho, so a contour was drawn in that location. As a result of the 50% DC for the KDE analysis, the hotspots of common dolphins in Korean waters were formed around the coast of Ulsan–Pohang, Donghae, and Sokcho (Figure 5). The coast of Ulsan–Pohang, among these hotspots in the ES, was the widest (Figure 5).

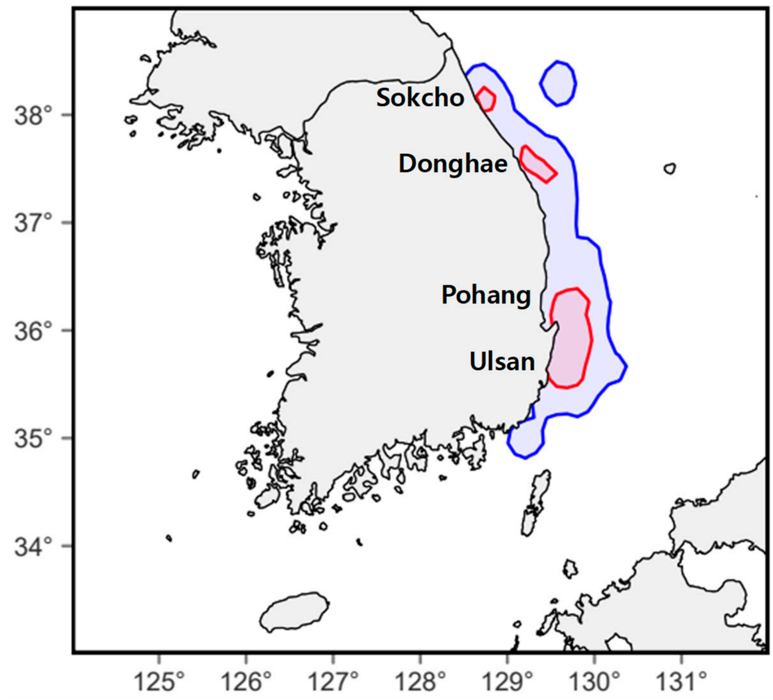

Figure 5. Density contours for 50% (red line) and 95% (blue line) kernels.

4. Discussion

Spatial information on the extent and area of habitat use is necessary to make spatial management decisions for animal conservation [36]. The polygon area drawn by the 100% MCP covered most of the Korean waters, except the YS, and seemed to be overestimated due to several of the outermost bycatch locations. Börger et al., 2006 [22], reported that methods rejecting a certain proportion of the outermost locations for MCP analysis lack any biological basis and do not eliminate biases. However, it is well-known that the 100% MCP is sensitive to abnormal behaviors of animals, such as excursional and exploratory behaviors leaving the home range, which can cause outliers [28,37]. As defined by Burt, 1943 [9], the home range covers the area used by an animal during its normal activities, such as mating and foraging.

Thousands of gill nets, which are one of the main types of fishing gear involved in common dolphin bycatch in Korean waters, are used in both the SS and the ES [18,38]. However, common dolphins were rarely bycaught around the SS (including Jeju-do) and Ulleung-do. Bycatch events of common dolphins in the SS and offshore regions of the ES occurred several times from 2011 to 2020 (Figure 2). Therefore, the home range boundary of common dolphins based on 95% MCP analysis is more reliable than that based on 100% MCP analysis. Furthermore, when comparing the boundary drawn by the 95% DC for KDE with that drawn by the 95% MCP, there was a small difference between the two boundaries drawn in the coastal region of the ES. Therefore, we suggest that the home range of common dolphins is limited from Busan to Sokcho along the coastal region of the ES in Korean waters. The SS and offshore region of the ES may be utilized as maritime routes of migration or excursions of common dolphins. How and why common dolphins use these sea areas will be a major research topic in the future.

Hotspots are areas that are not spatially fixed and can change over time. The effectiveness of spatial protection in the reduction of dolphin bycatch has already been noted [4]. Tomás and Sanabria, 2022 [2], showed recovery trends in populations of four marine mammal species, geographically placed in distant marine protected areas, providing empirical evidence that suggests the effectiveness of spatial management. Therefore, the protection of hotspots could be prioritized in spatial management decisions as long as they are continually monitored to ensure that they remain key areas for cetaceans. According to several prior studies [18,19], common dolphins have mostly been observed in the coastal regions of the ES. The present study further revealed the areas where hotspots of common dolphins exist within their home range by the 50% DC for KDE analyses. According to the analysis, it was suggested that their hotspots during study years were formed around the coast of Ulsan–Pohang, Donghae, and Sokcho within their home range.

Ecosystem productivity altered by nutrient enrichment may be considered an important biological factor affecting the formation of hotspots of cetaceans. According to Yoo and Park, 2009 [39], the waters around Ulsan–Pohang, delineated as the widest hotspot in the present study, constituted the most productive region, coupled with frequent coastal upwelling in the ES. Lee et al., 2017 [40], reported the waters around Ulsan–Pohang are used as a biological hotspot of minke whales. Kemper et al., 2013 [41], claimed that the increase in the records of pygmy right whales off Australia and New Zealand was related to the increase in coastal upwelling and productivity during climatic phenomena, such as El Niño, near their hotspots. Moura et al., 2012 [14], noted that a patchy distribution of common dolphins along the Portuguese coastline was associated with chlorophyll concentration. Manna et al., 2016 [42], described that bottlenose dolphins in the southern Mediterranean Sea prefer shallower feeding grounds that often host rich food webs, implying that chlorophyll-a is a useful parameter in identifying hotspots. However, it is difficult to improve the understanding of the formation of common dolphin hotspots because little is known about the biological and physical factors influencing changes in their spatial density in the ES. On the other hand, the hotspots of common dolphins are endangered or vulnerable habitats because the fishing grounds of various fisheries, such as those using set and gill nets, are formed around those hotspots, resulting in the bycatch of large numbers of common dolphins [38]. Further studies should be conducted seasonally and spatially on the seasonal distributions of common dolphins in the ES and appropriate fishing regulations (e.g., legal designations as protection areas, prohibited fishing periods, etc.) to reduce common dolphin bycatch.

Measures for reducing the risk of cetacean bycatch in fishing gear have been reviewed [43,44]. Moreover, several studies on technical mitigation measures for marine mammal bycatch have been conducted [45,46]. It is also a necessary initiative for the conservation of the common dolphin to extensively apply such mitigation measures to commercial fishing gear and vessels that operate within their home ranges. For example, in Korea, the use of excluder devices developed to prevent the bycatch of finless porpoises has been legally recommended to fishermen using stow nets in the YS [47]. However, in countries where fishery development is considered vital for food security or maintaining the balance of trade, cetacean bycatch action plans may be considered low-priority or politically unacceptable [48]. Furthermore, many fishermen realistically require a high financial reward and aid from the government to compensate for catch losses and bycatch reduction device (e.g., excluders and pingers) installation costs. In Korea, implementing a national policy of bycatch reduction of common dolphins in the coastal region of the ES also remains difficult. A preferential application of these mitigation measures to fishing gear and vessels operating within the waters around Ulsan–Pohang, identified as the widest hotspot in the coastal region of the ES, could be considered a feasible policy to reduce the bycatch of common dolphins with a lower social cost.

Jefferson et al., 2015 [12], illustrated that common dolphins are distributed from the YS to the ES. However, an interesting finding of the present study is that common dolphins are not distributed at all in the YS (Figure 2). In a similar case in Korean waters, finless porpoises were only distributed along the southern coast of the ES, YS, and SS [19]. According to Jefferson et al., 2015 [12], common dolphins are widely distributed in tropical to cool-temperature waters. MacLeod et al., 2007 [49], reported that this species in the Alboran Sea preferentially occurred in waters warmer than 12.3 °C. It is well-known that sea surface temperatures in the ES and YS are generally warmer than 10 °C in all seasons except for winter [50,51]. Namely, the coastal regions of the YS and ES are characterized by temperate waters except for in the winter. Alternatively, there is an apparent topographic difference in the coastal regions of the YS and ES. The coastal region of the YS consists of ria coasts and broad tidelands, while that of the ES has a topographic feature, where the depth after 200 m rapidly increases [52,53]. It seems that shallow waters, such as those in the coastal region of the YS, are not suitable habitats for common dolphins. In addition, Ahn et al., 2014 [54], reported that the prey species found in the stomach contents of common dolphins were mostly *Enoploteuthis chunii* (a squid species), common squid, and Pacific herring. In Korea, both common squid and Pacific herring were mostly caught in the ES [55,56]. Okiyama and Kasahara, 1975 [57] reported that *E. chunii* was also collected at a depth of around 300 m. The species assessed as the main prey of common dolphins were mainly distributed in the ES and at deeper depths. Pietroluongo et al., 2020 [16], reported that common dolphins show a preference for coastal waters due to the movement to epipelagic areas by small pelagic fish both in the western and eastern Mediterranean areas during warmer months, implying that the spatial distribution of the common dolphin could be caused by the spatial distribution of its prey (small pelagic fish). Therefore, the different distributions of common dolphins between the YS and ES may be caused by the composition and distribution of its prey species as a nutritional variable.

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