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Article

DISTRIBUTION OF SHORT AND LONG-BEAKED COMMON DOLPHIN MORPHS (*DELPHINUS* SPP.) BASED ON SKULL'S ROSTRUM INDEX ANALYSIS ALONG THE PERUVIAN AND CHILEAN COAST

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ABSTRACT. The distribution of the long-beaked and short-beaked common dolphin morphs in the eastern South Pacific is not well defined. The objective of this study was to propose a potential distribution of the two forms along the coast of Peru and part of Chile based on the rostral index obtained from the ratio of rostral length and zygomatic width. This phenotypic criterion was implemented in skulls deposited in museum collections in Peru and Chile. Based on classification, we were able to determine the distribution of each morphotype considering the collection location. A total of 44 skulls were analyzed, three of which did not have collection location. The results show that both forms of the common dolphins were distributed along the coast of Peru, but only the short-beaked common dolphin occurred in Chile. A larger number of short-beaked specimens were detected, especially in northern Peru. It was remarkable that the long-beaked was less common than expected since it is usually sighted in neritic waters. Around the 13° S latitude degrees seems to be an overlapping area with specimens of the two forms. Our study provides an analysis of the distribution of the two forms of common dolphins by implementing a discrimination index developed for North Pacific populations. Some patterns of segregation were observed, but this should be contrasted with a larger number of skulls and the application of other phenotypic criteria specific to the South Pacific.

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RESUMEN. DISTRIBUCIÓN DE DELFÍN COMÚN (*DELPHINUS* SPP.) DE HOCICO CORTO Y HOCICO LARGO EN BASE AL ÍNDICE ROSTRAL A LO LARGO DE LA COSTA PERU Y CHILE. La distribución de los morfotipos de delfín común de hocico largo y de hocico corto en el Pacífico suroriental no está claramente definida. El objetivo de este estudio fue proponer una distribución potencial de ambas formas de delfines comunes a lo largo de la costa de Perú y parte de Chile en base al índice rostral obtenido a partir de la relación del ancho cigomático y la longitud rostral. En esta investigación se implementa este criterio fenotípico en cráneos depositados en colecciones de museos del Perú y Chile. A partir de la clasificación, pudimos determinar la distribución de cada morfotipo considerando la localidad de colecta. El total de cráneos analizados fue de 44, tres de los cuales no contaron con localidad de colecta disponible. Los resultados indican que las dos formas de delfines comunes se distribuyeron a lo largo de la costa de Perú, pero en Chile solo estuvo presente el de hocico corto. Se detectó un mayor número de ejemplares de hocico corto, particularmente en las zonas del norte del Perú. Es notable que la variedad de hocico largo sea menos frecuente de lo esperado, ya que es usualmente reportado en aguas neríticas. Alrededor de los 13° de latitud sur sería un área donde se superponen ambas formas. Nuestro estudio proporciona un análisis de la distribución de las dos formas de delfines comunes mediante la implementación de un índice de discriminación desarrollado para poblaciones del Pacífico Norte y muestra algunos patrones de segregación que deben ser contrastados con una mayor cantidad de cráneos e implementado otros criterios fenotípicos más específicos para el Pacífico Sur.

Key words: Peru, Chile, delphinids, long-beaked, short-beaked, skull.

Palabras clave: Perú, Chile, delfínidos, hocico largo, hocico corto, cráneo.

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INTRODUCTION

Common dolphin (*Delphinus* spp.) forms a complex group of the Delphinidae family with several taxonomical reviews over the years. In the taxonomic history of the species, more than 20 different species have been described, until they were finally considered as local variations belonging to a single species *Delphinus delphis* Linnaeus, 1758 (Hershkovitz 1966). Later, Banks & Brownell (1969) suggested that log-beaked specimens from the Gulf of California should be recognized as *Delphinus bairdii* Dall, 1973 while short-beaked specimens from the oceanic waters of California should be considered as *Delphinus delphis.* In 1994, genetic and morphological analysis of sympatric short and long-beaked common dolphins in the eastern North Pacific provided evidence for two different species. Heyning & Perrin (1994) examined morphological characteristics and found differences in rostrum length and external coloration, but they considered that *D. bairdii* was a synonym of *Delphinus capensis* Gray, 1828. As a result, two species were proposed and accepted, the short-beaked form (*Delphinus delphis*) and the long-beaked form (*Delphinus capensis*) (Heyning & Perrin 1994). These differences were adopted in several works in the following years (Perrin 2009; Pompa Mansilla et al. 2010), even suggesting some reviews for the long-beaked form (Jefferson & Van Waerebeek 2002).

In recent years, Cunha et al. (2015) included molecular analysis using sequences of cytochrome b and found variability among different populations, however, that variability was not supported at species level for common dolphins in the western South Atlantic. As a result, the species *D. capensis* would not be valid for the western South Atlantic, and *D. delphis* was again considered the only valid species, with the exception long-beaked common dolphins from the northeastern Pacific, which could be a distinct species (*D. bairdii*). The authors recommended a revision of the taxonomy of *Delphinus* species and subspecies; in addition, the long-beaked common dolphins from the eastern North Pacific may constitute a different species (Cunha et al. 2015).

Sympatry in the distribution of short- and long-beaked groups is common in several marine regions (Bearzi 2005), especially in tropical and temperate waters (Heyning & Perrin 1994). Sympatry also occurs with other members of the family Delphinidae that are genetically very similar especially with

Stenella coeruleoalba (Lee et al. 2018). The short-beaked form is closely related to oceanic waters; it also occurs in the Atlantic and Pacific oceans (Perrin 2009; Tavares et al. 2010; Jefferson et al. 2008; Farías-Curtidor et al. 2017). Evidence for mixed groups or areas of overlap is scarce (Perrin 2009; Martínez et al. 2021) and the distribution of both morphotypes is related to geographical constraints.

Heyning & Perrin (1994) suggested that the rostral index (the ratio between rostrum length, RL, and zygomatic width, ZW) is a valid parameter for distinguishing specimens from the Northeastern Pacific and could even be used worldwide for diagnostic and species identification. High variability of the rostral length-zygomatic width ratio is observed both in the North Pacic and North Atlantic populations (Heyning & Perrin 1994; Murphy & Rogan 2006; Murphy et al. 2006) and in the South Atlantic population (Tavares et al. 2010; Ngqulana et al. 2019; Grandi et al. 2022).

The rostral index has also been proposed to distinguish specimens in the eastern South Pacific throughout the waters of Colombia, Ecuador, Peru, and Chile (Reyes & Molina 1997). However, there is no clear definition for the distribution of the morphotypes, and descriptions from other regions are implemented by default to infer the distribution of the common dolphin. The objective of this study is to use the rostral index (RL/ZW) to identify the morphotypes and their distribution according to |the locality of collection of each specimen.

MATERIALS AND METHODS

Cetacean collections on the coast of Peru were visited to analyze the skulls of common dolphins. In addition, two skulls from Chile were analyzed. The total number of studied specimens was 44 (Appendix 1).

The data were divided into three main areas, the northern in Peru (3°-7° S), the central area in Peru (7°-13° S), and the southern area in Peru and Chile (from 13°S to the south) (**Fig.** 1A). Only adult or mature individuals were considered for the analysis using the criteria proposed by Jefferson & Van Waerebeek (2002) and Jordan et al. (2015) for assessing cranial maturity. The fusion of premaxillae to maxillae $\geq$50% of the length of the rostrum and the advanced degree of bone fusion between other cranial bones were the criteria to discriminate adult vs juvenile skulls:

0 = no fusion, bones can be moved by applying low pressure.

1 = limited fusion, visible suture line.

2 = advanced fusion, suture line partially visible or not visible.

Specimens were assigned to one of the two forms, short-beaked and long-beaked, using the rostral index (Heyning & Perrin 1994). The rostral index consists of two linear measures: rostrum length and zygomatic width. The rostral index was defined as follows:

$$RI=\frac{RL}{ZW}$$

Where RL is the length of the rostrum and ZW is the zygomatic width. RI between 1.2 and 1.5 determines the short-beaked form, while LR between 1.52 and 1.77 is used for the long-beaked form (Heyning & Perrin 1994; Reyes & Molina 1997).

In addition, the total length of the skull (condylobasal length, CBL) was used as a proxy for the total length of the animal to test for differences in distribution according to the size of the animal among areas, but independent of the morphotype. All linear measurements were obtained to the nearest millimeter using a Truper® digital vernier. The reference for the measurements is the work of Murphy et al. (2006). The same author (LS) conducted all measurements on all specimens.

A contingency table with Fisher's exact test was used with $\propto$ = 0.05 to test for significant associations among common dolphin forms and areas (northern Peru, central Peru, and southern Peru-Chile). For the CBL analysis, two groups were considered (northern and central + southern groups) due to the small number of specimens collected on the central and southern coasts. All statistical analyses were conducted using PAST 4.07b software (Hammer et al. 2001).

The forms of the specimens were located on a SIG map according to the collection site. Most of the specimens came from stranding events, a reduced group was obtained from bycath in artisanal fishery. Regardless of origin, the majority of specimens had data from the collection locations and this data was taken into account to determine the location of origin of the specimen (**Table** 1). Only three skulls did not have collection location however, all of them were collected in Peru.

Table 1

Long-beaked and short-beaked forms distribution on coastal areas.

	North	Central	South
Long-beaked	8	6	3
Short-beaked	21	1	2

RESULTS

The short-beaked form was predominant in the northern area (**Fig.** 1A) and throughout the study area but in reduced numbers in the central and southern areas (**Fig.** 1A). The long-beaked form was less commonly found in the collections, **Figure** 1B shows a zoom of the distribution area for this form. Representative views of the skulls of specimens of the long-beaked and short-beaked forms are presented in **Figure** 2. There was an apparent domi-

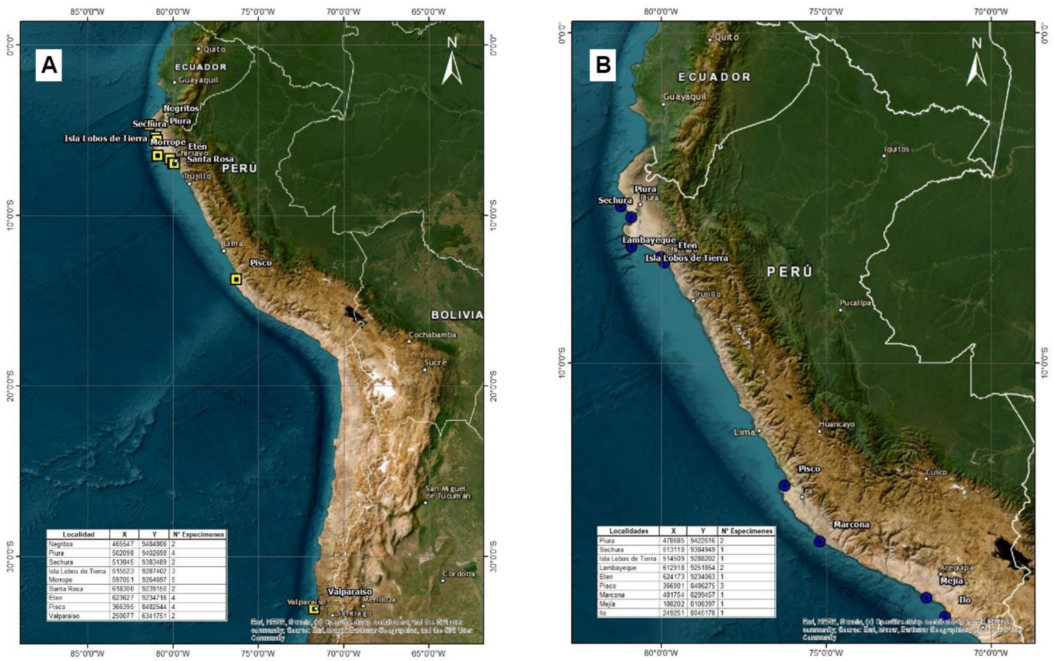

Fig. 1. Study area and distribution of short-beaked (A) and long-beaked (B) common dolphin.

Table 2

Residual Bonferroni-corrected p-values of the contingency table for Fisher exact test applied to the two morphotypes for each coastal area.

	North	Central	South
Long-beaked	0.0303	0.0544	1
Short-beaked	0.0303	0.0544	1

nance of short-beaked form on the northern coast (Fisher's exact test = 0.0083, $p < 0.05$) (**Table** 2). The same was observed for the long-beaked despite the reduced number of specimens. On the other hand, RI values for the north coast were mainly under the threshold value determined by Heyning & Perrin (1994), and those from the central coast are mainly over the threshold (**Fig**. 3). A Kruskall-Wallis test revealed a significant difference between the medians of the sample (Hc = 9.5, $p < 0.05$), mainly between the north and center coasts ($p < 0.05$). However, our sample size is small, and this pattern must be confirmed by a larger number of skulls.

The skull total length (CBL) showed a normal distribution (Shapiro Wilk test; $p < 0.05$). The differences in the CBL between long-beaked and short-beaked were statistically significant ($t = 2.9659$, $p < 0.05$) (**Fig**. 4). The CBL is more variable in the long-beaked form ($x = 472.59$, $S^2 = 1341.3$) than in the short-beaked form ($x = 445.95$, $S^2 = 534.43$). An ANOVA test did not detect significant differences in animal size (based on CBL as a proxy) according to zone ($F = 0.008$, df = 1, $p > 0.05$). Common dolphins of different sizes and different forms could be found indistinctively in both northern and central/southern areas.

DISCUSSION

We found an extensive distribution of common dolphins along the study area but with some particularities for each form. The northern distribution area in Peru extended from 4° to 6° S, while southern distribution areas in Peru encompasses 13° to 18° S. This is similar to the distribution identified by Llapapasca et al. (2018) based on sightings from cruise surveys for small pelagic fish in neritic and oceanic waters, where areas of concentration of common dolphins were associated with upwelling centers (Zuta & Guillén 1970; Morón 2000). Common dolphins have high morphological and genetic variability as an adaptation to local or regional oceanographic conditions (Jefferson & Van Waerebeek 2002; Pompa

Fig. 2. Dorsal view of skulls of short-beaked (A) and long-beaked (B) specimens of *Delphinus* spp.

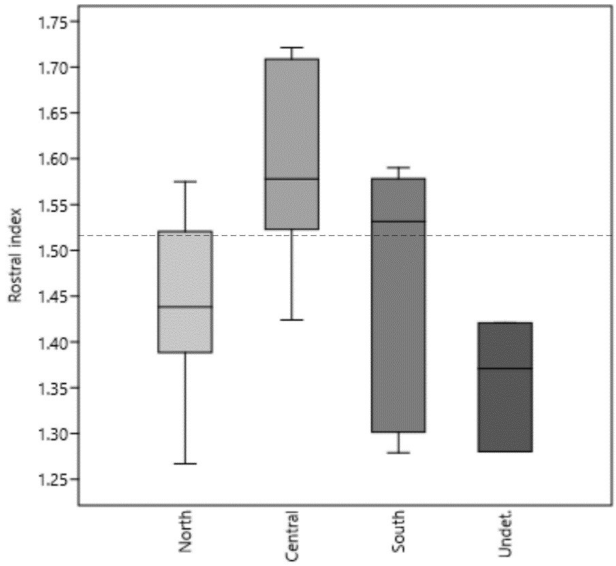

Fig. 3. Rostral Index (RI) for each area of measured specimens (n = 44). The dashed line indicates the limit value established by Heyning & Perrin (1994) for diagnosis to long or short beaked skulls.

Mansilla et al. 2010; Tavares et al. 2010; Lee et al. 2018). The distribution of long-beaked and short-beaked forms on the coast of Peru and Chile is related to the Humboldt current ecosystem and local coastal variability on shelf extension, currents movements, salinity, and sea surface temperature (Llapapasca et al. 2018).

Sighting data of common dolphins in Peru distinguished long-beaked and short-beaked forms with their previous specific denominations of *Delphinus capensis* and *Delphinus delphis*, respectively (Reyes 2009; Llapapasca et al. 2018; Pacheco et al. 2019). Based on hundreds of dolphins captured in coastal waters off central and north-central Peru by artisanal and semi-industrial fisheries in the 1980-1990s, the long-beaked form accounted for more than 99% of landings (e.g., Van Waerebeek & Reyes 1994; Van Waerebeek et al. 1994, 2002). This result is consistent with the fact that the long-beaked form being the most common in sighting records directly related to neritic waters at 5-7° S, 9-12° S and 17-18° S (Llapapasca et al. 2018), while short-beaked form is better known from oceanic waters (Jefferson et al. 2008; Reyes 2009). In this study of stranded dolphins, there is a higher number of short-beaked specimens, especially in the northern area. This is the opposite pattern expected since the long-beaked form was previously documented as being the predominant bycaught morph, as north as Chimbote (9°S) (Van

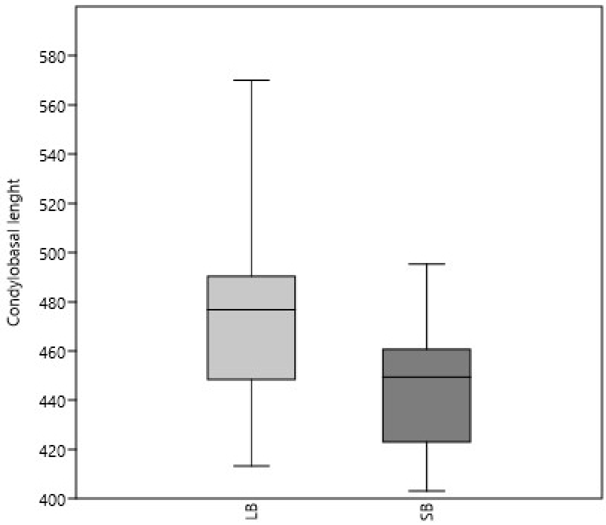

Fig. 4. Skull condylobasal length variability between *D. delphis* specimens of long-beaked (LB) and short-beaked (SB) form.

Waerebeek & Reyes 1994), based on landing ports and strandings.

However, it is remarkable that long-beaked stranded skulls are less frequent than expected, and probably most of the sighting records would underestimate the occurrence of the short-beaked form. One fact to consider is that the skulls analyzed in this study came mainly from stranded animals, so those specimens had been collected randomly. Therefore, there is not bias for one or another form in the collections.

Ecologically, the long-beaked inhabits waters over the continental shelf, while the short-beaked is distributed in offshore and shelf-break areas (Llapapasca et al. 2018). The composition of the prey in the stomach contents of the long-beaked morph in Peruvian waters indicates that they occupy the neritic foraging habitats in the Humboldt Current System (García-Godos et al. 2007). In the Atlantic and Pacific Oceans, as well as in the Mediterranean Sea, the short-beaked form is more related to oceanic waters; while the long-beaked form would have a patchy coastal distribution, occurring in the Northeastern and Southeastern Pacific, Japan, Southwestern and Southeastern Atlantic, Venezuela, and the Indian Ocean (Perrin 2009; Tavares et al. 2010; Jefferson et al. 2008; Farías-Curtidor et al. 2017). The distribution found in our work points to the long-beaked would be better related to cold and coastal waters of the Humboldt System, while the short-beaked would be linked to oceanic conditions. Accordingly, the long-beaked form would be closely related to the subspecies *Delphinus delphis bairdii*. However, our data is preliminary, and more specimens and more evidence should be examined to determine this. There is not a complete restriction in the distribution of the two forms of common dolphin in our study there would be potential areas of overlap, particularly in the northern area at 4° to 6° S and in the central area in the 13° S. Sympatry in the distribution of short- and long-beaked groups is known primarily in tropical and temperate waters (Heyning & Perrin 1994; Bearzi 2005; Tavares et al. 2010; Cunha et al. 2015; Ngqulana et al. 2019; Grandi et al. 2022). Sympatry also occurs with other members of the family Delphinidae which has a close genetic similarity with the common dolphin, especially *Stenella coeruleoalba* (Lee et al. 2018). Our results suggest that there is an overlap in the distribution of the two forms of the common dolphin, mainly on the northern and central coast of Peru. The analyzed skulls were mostly found on beaches. The collection location represents the specific place where the specimen was found, it would not necessarily represent the specific place where the individual lived or their longitudinal distribution. Nevertheless, the presence of a skull on a beach provides very useful referential information to determine a preliminary distribution based mainly on latitudinal occurrence.

In the case of the southern area, the specimens from Peru belonged to the long-beaked form, and the two specimens from Chile (33° S) were confirmed as short-beaked form. In our study there is gap of data from 17° S to 33° S. However, it does not mean that common dolphins do not exist. Aguayo-Lobo et al. (1998) reported that short-beaked common dolphins are found from Arica (18° S) to Puerto Montt (40°), and incidental captures in fisheries have confirmed the occurrence in northern Chile (Arica, Iquique, Tocopilla and Mejillones) (González-But & Sepúlveda 2016). In our analysis, the two specimens from Valparaiso confirm the reported occurrence (Sanino et al. 2003; Cárdenas et al. 1991) and extensive distribution of the short-beaked form in Chilean waters.

According to our data, the short-beaked form has a wide distribution area from northern Peru to the coast of central Chile in Valparaiso. The southern known record for this form was reported at 33°27'S, 78°53'W in far offshore waters off Archipielago Juan Fernández in Chile, where a small pod of 10 individuals was observed (Sanino et al. 2003). There is also an adult stranded male collected on Isla Alejandro Selkirk, in the same archipelago, identified as *D. delphis* by K. Van Waerebeek (pers. comm. to LS, Cárdenas et al. 1991). On the coast of Peru, the short-beaked form seemed to be rare in the central zone and absent in the south (**Fig**. 1A), although there has been limited sampling in the latter area. The long-beaked form was restricted to the coast of Peru (**Fig**. 1B), being present both in the north, center and south coasts. However, there are some records in Chile (Cárdenas et al. 1991; Sanino et al. 2003) that confirm that the long-beaked occurs in Chilean waters. The higher variability observed in the CBL of the long-beaked could be the result of phenotypic plasticity along its distribution range. Llapapasca et al. (2022) found that the distribution of common dolphin in Peru is correlated to productive cold waters with a shallow oxygen minimum zone; this would produce habitats specificity to promote the phenotypic plasticity of the long-beaked form. Both forms overlap on the northern coast of Peru, mainly in Lambayeque and Piura, as well as in the central coast in Pisco.

Our analysis provides an explanation for the distribution of the common dolphin using the rostral index to discriminate the two forms. Using this morphological criterion, we were able to determine that the long-beaked is not the most frequent form among the stranded skulls, despite recent sighting data, massive samples obtained through historical by-catch monitoring, and niche boundaries theoretically assigned to the two forms. Admittedly, the different results may at least in part, be due to different sampling biases, including temporal shifts as well as the small size of our cranial sample. In addition, rostral index values taken from the NE Pacific might not be completely discriminant by themselves to differentiate morphs in the SE Pacific, and other morphological criteria should be included in future studies to support our findings or to provide a stronger distribution description. In addition, the distribution of the long-beaked form would be more associated with the coast of Peru, although not completely restricted to this, and the short-beaked form is found along Peru and Chile coast but is theoretically restricted by certain oceanographic conditions. Finally, there would be overlap on more than one area, especially in the northern coast of Peru. However, whether this overlap occurs eventually or is frequent is beyond the scope of the results of this study and should be evaluated in the future. Knowing on a better scale the distribution of each form of common dolphin would help us understand the state of the ecosystem, as they are predators and important regulators of hydrobiological resources.

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Appendix I: List of specimens of *Delphinus* spp. and collection data.

Collection code	Collection	Locality	Rostral Index	Morphotype
MUSM 7183	Museo Universidad de San Marcos	Pisco	1.5985	Long-beaked
MUSM 8338	Museo Universidad de San Marcos	Pisco	1.578	Long-beaked
MUSM 20879	Museo Universidad de San Marcos	Sechura	1.543	Long-beaked
MUSM 20882	Museo Universidad de San Marcos	Sechura	1.464	Short-beaked
MUSM 20881	Museo Universidad de San Marcos	Sechura	1.384	Short-beaked
MUSM 7182	Museo Universidad de San Marcos	Pisco	1.542	Long-beaked
MUSM 8349	Museo Universidad de San Marcos	Pisco	1.423	Short-beaked
MUSM 8346	Museo Universidad de San Marcos	Pisco	1.522	Long-beaked
MUSM 8345	Museo Universidad de San Marcos	Pisco	1.708	Long-beaked
MUSM 8347	Museo Universidad de San Marcos	Pisco	1.721	Long-beaked
MUSM 52625	Museo Universidad de San Marcos	Mórrope	1.369	Short-beaked
MUSM 52626	Museo Universidad de San Marcos	Mórrope	1.471	Short-beaked
D3	Museo Universidad de San Marcos	Mórrope	1.525	Long-beaked
D4	Museo Universidad de San Marcos	Mórrope	1.415	Short-beaked
D5	Museo Universidad de San Marcos	Mórrope	1.368	Short-beaked
LAS-203	NGO Prodelphinus	Lobos de tierra Island	1.434	Short-beaked
LAS-23	Author collection	Lobos de tierra Island	1.358	Short-beaked
LAS-37	Author collection	Lobos de tierra Island	1.516	Long-beaked
LAS 191	Author collection	Lobos de tierra Island	1.418	Short-beaked
I	Author collection	No data	1.280	Short-beaked
II	Author collection	No data	1.420	Short-beaked
III	Author collection	No data	1.370	Short-beaked
MNHN/MAM 1488	Santiago de Chile Museum	Valparaiso	1.323	Short-beaked
MNHN/MAM 1580	Santiago de Chile Museum	Valparaiso	1.278	Short-beaked
G0145	Instituto de Paleontología-Universidad Nacional de Piura	Piura	1.539	Long-beaked
G0143	Instituto de Paleontología-Universidad Nacional de Piura	Piura	1.438	Short-beaked
1.Negritos Anthony Deza	Instituto de Paleontología-Universidad Nacional de Piura	Negritos	1.391	Short-beaked
G0146	Instituto de Paleontología-Universidad Nacional de Piura	Piura	1.545	Long-beaked
2.Negritos Anthony Deza	Instituto de Paleontología-Universidad Nacional de Piura	Negritos	1.274	Short-beaked
G-0144	Instituto de Paleontología-Universidad Nacional de Piura	Piura	1.448	Short-beaked
IP290	Instituto de Paleontología-Universidad Nacional de Piura	Piura	1.510	Short-beaked
IP 291	Instituto de Paleontología-Universidad Nacional de Piura	Piura	1.308	Short-beaked
MUSA19651	Museo Universidad Nacional de San Agustín	Mejía	1.531	Long-beaked
No code	Museo Universidad Nacional de San Agustín	Ilo	1.590	Long-beaked
MHNPRG0066	Museo Universidad Nacional Pedro Ruiz Gallo	Lambayeque	1.575	Long-beaked
MHNPRG0067	Museo Universidad Nacional Pedro Ruiz Gallo	Lambayeque	1.546	Long-beaked
LAS221	Museo Universidad Nacional Pedro Ruiz Gallo	Eten	1.552	Long-beaked
LAS 220	Museo Universidad Nacional Pedro Ruiz Gallo	Eten	1.421	Short-beaked
LAS 226	Museo Universidad Nacional Pedro Ruiz Gallo	Eten	1.505	Short-beaked
LAS 225	Museo Universidad Nacional Pedro Ruiz Gallo	Eten	1.472	Short-beaked
LAS 223	Museo Universidad Nacional Pedro Ruiz Gallo	Eten	1.416	Short-beaked
No code	Laboratorio costero de IMARPE en Santa Rosa	Santa Rosa	1.392	Short-beaked
No code	Laboratorio costero de IMARPE en Santa Rosa	Santa Rosa	1.267	Short-beaked
No code	Proyecto Punta San Juan	San Juan de Marcona	1.566	Long-beaked