



Migratory Behavior of an Eastern North Pacific Gray Whale From Baja California Sur to Chirikov Basin, Alaska

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Eastern gray whales undertake annual migrations between summer feeding grounds in the Bering and Chukchi Seas and winter breeding and calving lagoons in the west coast of Baja California, Mexico. On February 12, 2017, three adult gray whales were sighted at San José del Cabo, Mexico, in which one individual, named “María,” was tagged using a satellite telemetry transmitter (PTT). The PTT stopped the signal on July 11, 2017. María traveled 11,387 km during 149 days from San José del Cabo to the Chirikov Basin. The migration route was aligned close to the coastline (<23 km) from February to April. After passing Kodiak Island in May, María started traveling far away from the coastline (>70 km) into the Bering Sea, including the Chirikov Basin. During March, April, and May, María traveled long distances at relatively high speeds, in contrast to the lower speed during February, early March, and the arrival time to the feeding areas in May, June, and July. The total distance traveled by María during its migration from Ojo de Liebre Lagoon to the Chirikov Basin was 8,863 km during 61.5 days with an average speed of 5.5 km h⁻¹; this excludes the 14 days and 591 km that María spent feeding on the coast of Kodiak Island in late April. The information provided by this tagged whale documents a single whale’s migration, which is consistent with previous studies and constitutes the most complete northbound reported migration of an eastern gray whale.

Keywords: gray whale, migration, behavior, satellite tag, eastern North Pacific

INTRODUCTION

Two extant Pacific populations of gray whales, *Eschrichtius robustus*, are currently recognized. The eastern North Pacific (ENP) population of 20,580 (95% CI = 18,700–22,870) individuals (Stewart and Weller, 2021) and occurs in the ENP and the Arctic Ocean between North America and Asia. The western North Pacific (WNP) population of 271–311 whales (Cooke et al., 2018) occurs along the North Pacific Asian coast, with some individuals migrating to the Mexican breeding and calving lagoons (Weller et al., 2012).

Scammon (1874) first recognized gray whales as long-distance migrants as he observed Alaskan hunting implements in individuals harvested in Mexico. Since then, the coastal migration of ENP gray whales has been described by numerous researchers. Gray whales undertake annual migrations

between summer feeding grounds in the Bering and Chukchi Seas and winter in the breeding and calving lagoons in the western coast of Baja California, Mexico (Gilmore, 1960; Rice and Wolman, 1971; Sumich, 1983; Berzin, 1984; Moore et al., 1986; Swartz, 1986).

From late-May to early-October, the ENP population's core remains on its feeding areas in the shallow coastal and shelf waters between Alaska and Russia and along their northern coastlines. Until the late-1990s, the north Bering Sea, especially the Chirikov Basin and the southern Chukchi Sea, were the primary feeding grounds as they supported benthic amphipod prey (Swartz, 2018). However, recent ecosystem shifts in the northern Bering Sea have resulted in a decline in benthic productivity, affecting the distribution of prey species, and consequently, the summer distribution of gray whales (Moore and Huntington, 2008). In turn, gray whales have responded by shifting their foraging distribution to areas with presumable reliable prey sources, including the Gulf of Alaska, the southeastern Bering Sea, the southern Chukchi Sea, and the western Beaufort Sea.

The southward migration initiates in the fall, with females in late pregnancy leading, followed by adults and immature females, and lastly by immature males. They exit the Bering Sea *via* the Unimak Pass, Alaska, and follow the Alaskan, Canadian (British Columbia), Californian, and Mexican coastline (Rice and Wolman, 1971; Rugh et al., 2001). The trip averages 2 months, during which mating begins and continues in the winter congregation areas (Jones and Swartz, 1984).

Gray whales spend about 3 months in the Mexican wintering areas, where they mate and give birth between December and April (Jones and Swartz, 1984; Swartz, 1986). While whales have typically departed from the Baja lagoons by late March, the northward migration continues elsewhere along the coast of North America until about June, when the final phase of the migrating whales arrives in the northern feeding areas. Whales continue to feed in the north until late fall, at which time they begin their southward migration to the breeding and calving areas in Mexico (Rice and Wolman, 1971; Braham, 1984; Moore and Ljungblad, 1984).

Mate and Urbán (2003) carried out the first telemetry study regarding the speed and route of individual gray whales over long distances. The authors recorded one adult's track (1,794 km) from San Ignacio Lagoon, Mexico, to the north of San Francisco, United States. Mate (2006) tagged seventeen gray whales in Ojo de Liebre lagoon in March 2005; six whales were tracked until their feeding grounds in the Bering and Chukchi Seas. Unfortunately, they have several gaps in the signal recording during the migration route, particularly in the Gulf of Alaska, where there was no information from any tagged whales. Moreover, Ford et al. (2013) documented the migration route taken by northward migrating gray whales during spring between Vancouver Island and southeastern Alaska, approximately 575 km. Afterward, Mate et al. (2015) recorded the first complete migration route of a WNP female adult gray whale named "Varvara" from Sakhalin Island, Russia, tagged in August 2011, to the west coast of the Baja California Peninsula and her return to Russian waters in May 2012 (Mate et al., 2015).

In the present study, we present detailed information regarding the route, timing, and distance of the migration of an ENP gray whale, including the inference of its behavior, from San José del Cabo, in the southern tip of the Baja California Peninsula, Mexico, to the Chirikov Basin, Alaska, in the Bering Sea.

METHODS

A satellite telemetry transmitter (PTT; Wildlife Computers SPOT6 AM-193N) was used to record a gray whale's speed and behavior during its migration route. The PPT duty cycle was scheduled to transmit every 6 h for 3 months, followed by once a day for the next 3 months, and every other day until the PTT stopped transmitting.

The PTT was washed with soap and water under laboratory conditions and treated with formaldehyde at 10% and ethanol at 70% as antiseptics. It was then drenched with oxytetracycline as an antibiotic and immediately wrapped in plastic to preserve sterility. Finally, it was sprayed with Neobol® (Clostebol Acetate: Neomycin Sulfate) before being placed on the whale.

From a small boat (8 m long) in motion, the PTT was inserted 10–25 cm below the dorsal fin on the left back of the whale, using a modified pneumatic line thrower (ARTS Whale Tagger, Restech Inc., Bodø, Norway) with an air pressure of 10–15 bar (10–15 kg cm⁻²). Two rings of steel petals anchored the device. The behavior of the whale and the successful tagging were monitored immediately. All procedures were reviewed and approved by the Animal Care and Use Committee of the Smithsonian Tropical Research Institute.

The locations received from the PTT were received through the Argos satellite system. These locations were filtered using the "Argos filter" library (Freitas et al., 2008) in R (R. 3.6.2. Development team, 2013). Regarding the behavioral state, the filtered data was fitted to a State-Space Model (SSM) using the R package "bsam" (Jonsen, 2016). The SSM was fitted with 30,000 Markov Chain Monte Carlo (MCMC) samples, where the first 10,000 iterations were discarded as a burn-in. The remaining interactions were decreased by eliminating one in five (Jonsen et al., 2005; Bailey et al., 2009). This model provided a behavior mode of 1 (mean MCMC values < 1.25) considered as "transit behavior" or 2 (values > 1.75) as "area restricted search" behavior (ARS, foraging or breeding). The locations with mean values between these cutoffs were labeled "uncertain" (Jonsen et al., 2005, 2007; Breed et al., 2012).

Post-Processing. Data on land was corrected by constructing ellipses to create centroids and calculate the Python script (Jiménez López et al., 2019; Mate et al., 2019). The tracks were built in the Geographic Information System ArcGIS Pro software [v2.6 Environmental Systems Research Institute (ESRI)] from which the speed and distance between pairs of locations were calculated using the behavior mode in Python (ESRI, 2015; Mate et al., 2019). The depth values were extracted from GEBCO 2019 Gridded Bathymetry¹ in ArcGIS Pro by the extract values tools. The coastline's distance was calculated on ArcGIS Pro through

¹<https://download.gebco.net/>

TABLE 1 | Summary of the obtained data by the satellite transmitter placed on María from San José del Cabo, BCS, Mexico, to the Chirikov Basin, 2017.

Migration segment	Month	Total days	Total distance (km)	Speed (km/h)			Speed by Behavioral mode (km/h)		
				Mean (SD)	Min	Max	Transiting (SD)	ARS (SD)	Uncertain (SD)
Mexico	February	16	1,015*	2.4 (±1.9)	0.12	7.6	4.9 (±0.8)	1.6 (±1.1)	1.8 (±1.8)
Mex-United States	March	31	3,508	4.7 (±3.4)	0.07	21.5	5.8 (±3.2)	1.1 (±0.9)	0.9 (±0.5)
CAN-Alaska	April	30	2,805	3.9 (±2.8)	0.12	15.8	5.1 (±2.5)	1.0 (±0.9)	2.0 (±1.4)
Alaska-Chirikov Basin	May	31	3,047	4.1 (±2.5)	0.06	12.0	5.3 (±1.9)	1.0 (±0.6)	2.0 (±1.2)
Chirikov Basin	June	30	691	1.0 (±0.7)	0.18	3.6	–	1.0 (±0.7)	1.4 (±0.5)
	July	11	320	1.2 (±1.2)	0.04	5.3	–	0.8 (±0.7)	2.7 (±1.4)
	Total	149	11,387	3.2	0.4	11.2	5.3	1.1	1.8

*During February, María did not send any single data for 5 days; therefore, the distance (along the coastline between San José del Cabo and Magdalena Bay) was calculated in a GIS software (ArcGIS Pro v. 2.6), 350 km approximately, and added to the distance calculated by the Argos locations for the total approximation distance.

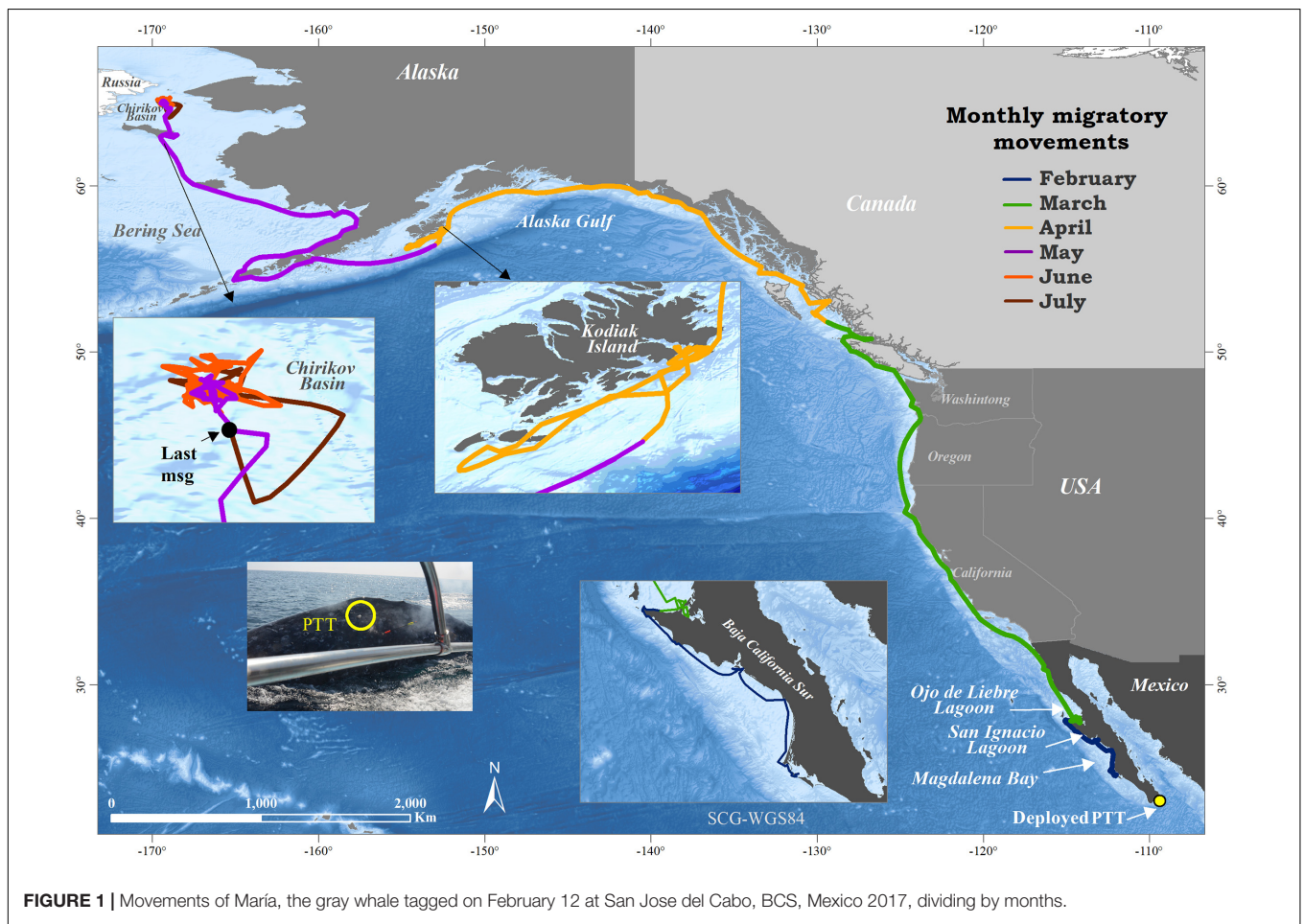


FIGURE 1 | Movements of María, the gray whale tagged on February 12 at San Jose del Cabo, BCS, Mexico 2017, dividing by months.

spatial analysis based on a spatial location called Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) from NOAA².

It is important to note that the PTT began to send signals 5 days after it was deployed on the gray whale, explaining the observed gap in the track between San José del Cabo and Bahía Magdalena, B.C.S., Mexico. San José del Cabo’s distance

to Magdalena Bay was estimated using an imaginary line drawn along the coast on a direct path to Magdalena Bay after the transmitter was placed. The total track and behavior were displayed in time and space.

RESULTS

On February 12, 2017, three adult gray whales were sighted at San José del Cabo (23.06505 N, 109.53485 W), and one

²<https://www.ngdc.noaa.gov/mgg/shorelines/>

TABLE 2 | Summary of María's tracking data at the breeding area, migration route, and feeding areas during 2017.

Activity	Start date (d/m/y)	Speed (km/h)					Transiting (47%)					ARS behavior (40%)					Uncertain (13%)				
		Total days	Total distance (km)	Mean (SD)	Min	Max	Total days	Dist. (km)	Speed (km/h) Mean (SD)	Loc* (%)	Total days	Dist. (km)	Speed (km/h) Mean (SD)	Loc (%)	Total days	Dist. (km)	Speed (km/h) Mean (SD)	Loc (%)			
Reproduction** (BCS)	12/02/2017	25	1,294	2.0 (±2.0)	0.07	10.9	4	360	1.3 (±0.5)	2.1	10	241	1.3 (±1.0)	5.5	6	343	1.6 (±1.6)	6.2			
Migration (OLL-Kodiak)	09/03/2017	38	5,378	5.9 (±2.8)	1.20	21.5	38	5,378	1.5 (±0.7)	26	-	-	-	0	-	-	-	0			
Feeding (Kodiak)	16/04/2017	14	591	1.8 (±1.5)	0.12	6.6	5	273	0.6 (±0.4)	3.1	7	134	1.0 (±0.9)	4	2	184	2.0 (±1.4)	2.4			
Migration (Kodiak-CB)	30/04/2017	24	2,916	4.9 (±2.1)	0.44	12	23.5	2,795	1.3 (±0.5)	16	-	-	-	0	0.5	121	2.0 (±1.4)	2.1			
Feeding (CB)	24/05/2017	48	1,208	1.0 (±0.9)	0.04	5.3	-	-	-	0	46	979	0.9 (±0.7)	30.4	2	229	2.4 (±1.3)	2.6			
End signal (CB)	11/07/2017																				
Total		149	11,387	3.2	0.4	11.2	71	8,806	4.7	47	63	1,354	1.1	40	11	877	2.0	13			

*Loc, Argos locations.

**In this section, the speed and behavioral mode were calculated for the 20 days that the PPT sent a signal. Likewise, the distance from San José del Cabo to Magdalena Bay was calculated in a GIS software (ArcGIS Pro v2.6, 350 km approximately) and added to the track recorded by the satellite data in the breeding area.

individual (sex unknown) named “María,” was tagged. In Spanish, María is a common surname to both women and men, and we considered it appropriate since the sex of the tagged whale remains unknown. The PTT stopped sending a signal on July 11, 2017. During this time, 2,335 locations were generated, and a total of 579 locations were considered of good quality to build the track.

María traveled 11,387 km during 149 days from San José del Cabo to the Chirikov Basin. The migration route was aligned close to the coastline (<23 km) from February to April. After passing Kodiak Island in May, María started traveling far away from the coastline (>70 km) toward the south coast of the Aleutian Islands in the direction of Korovin Island. It then continued to the Unimak Pass, where it went into the Bering Sea. María traveled close to the Aleutian Islands’ north coast to Bristol Bay and afterward to the Chirikov Basin (Table 1). All the travel took place in waters less than 200 m of depth except for March, where it traveled in deeper waters off the narrow continental shelf of southern California and the Oregon coast (Table 1 and Supplementary Figure 1).

After María was tagged in San José del Cabo on February 12, it was not heard from until it reached Bahía Magdalena. On February 17, 5 days and approximately 350 km after, the tag began to send signals to the satellite. María spent a few days in Magdalena Bay and then moved to San Ignacio Lagoon and Ojo de Liebre. During March, April, and May, María was traveling long distances at relatively high speeds (3.05, 2.80, and 3.05 km h⁻¹, respectively); in contrast to the lower speed during February, early March, and the arrival time to the feeding areas in May, June, and July. On March 9, María began its northbound migration by traveling straight up along the Pacific coast up to Kodiak Island, where it stayed for 2 weeks. The whale continued its migration to the Bering Sea and stopped at Chirikov Basin in the last week of May, where it remained until July 11, 2017 (Table 1 and Figure 1).

From February 17 to March 8, the whale exhibited ARS behavior while in San Ignacio Lagoon ARS behavior was present when María visited San Ignacio Lagoon and Ojo de Liebre Lagoon. During its migration from March 9 to May 24, its behavior was mainly “transit,” with some ARS behavior registered in late April when María spent 14 days on the southeast coast of Kodiak Island. Finally, the ARS behavior was present 98% of the time in the feeding area of the Chirikov Basin (Table 2 and Figure 2).

DISCUSSION

The northbound migration of gray whales begins with solitary whales (adults without a calf) during the second half of February (Rice and Wolman, 1971; Jones and Swartz, 1984; Swartz, 1986). Two whales without a calf tagged in San Ignacio Lagoon in the winter of 1996 started their northbound migration on February 10 and 15 (Mate et al., 2003); this was also true for Varvara, the WNP gray whale from the Russian feeding ground, who began her lone northbound migration on February 26 (Mate et al., 2015).

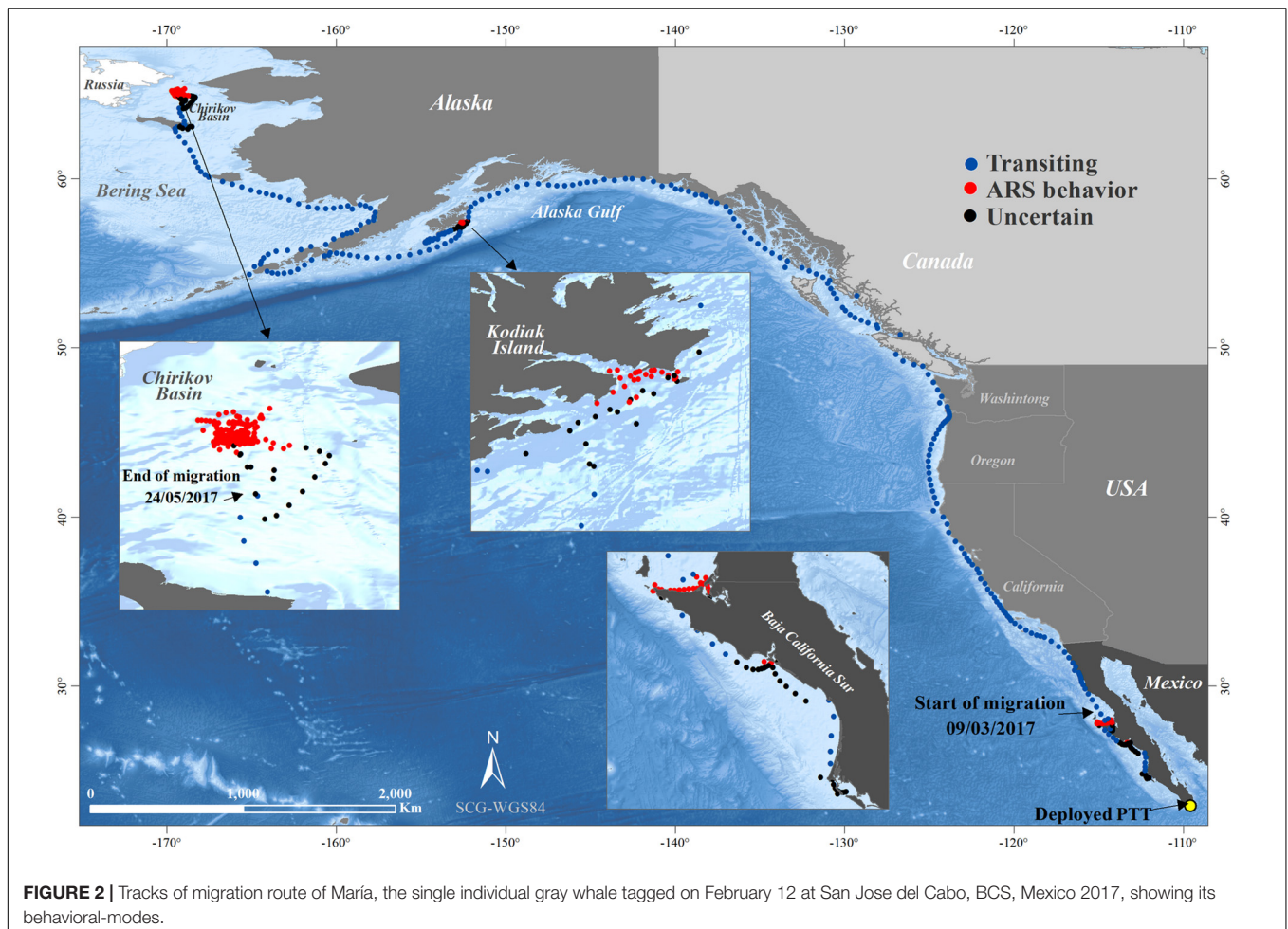


FIGURE 2 | Tracks of migration route of María, the single individual gray whale tagged on February 12 at San Jose del Cabo, BCS, Mexico 2017, showing its behavioral-modes.

The gray whales and the bowhead whales are the only baleen whales that travel nearshore during their migration (Braham et al., 1980; Swartz, 1986). According to Rice and Wolman (1971), gray whales take the most direct route when crossing bights or coastal indentations, such as the Channel Islands in California and the Vizcaino Bay in the Baja California Peninsula. María followed this pattern, except on the coast of Oregon and the Queen Charlotte Sound in British Columbia, where it traveled at a distance between 50 and 90 km of the coast. Ford et al. (2013) showed similar routes in the coasts of British Columbia and Southeast Alaska. Both Varvara and María entered the Bering Sea through Unimak Pass, the usual migratory route for gray whales (Rice and Wolman, 1971).

The total distance of María's migration from Ojo de Liebre Lagoon to the Chirikov Basin was 8,863 km for 61.5 days at an average speed of 5.5 km h⁻¹; this excludes the 14 days and 591 km that María spent feeding on the coast of Kodiak Island in late April. This migration route is shorter than the migration of Varvara, who traveled 10,548 km from Ojo de Liebre Lagoon to the Sakhalin Island, Russia, for 78.8 days. Nevertheless, the migration speed (5.5 km h⁻¹) was similar. Mate and Urbán (2003) reported an average speed of 5.2 km

h⁻¹ on the migration of a gray whale from San Ignacio Lagoon until the north of San Francisco, where the tag stopped the transmissions. The average migration speed of the gray whale is higher than other migratory baleen whales: 4.0 km h⁻¹ in humpback whales (Lagerquist et al., 2008); 4.0 km h⁻¹ in bowhead whales (Zeh et al., 1993); and 3.7 km h⁻¹ in blue whales (Bailey et al., 2009).

Area Restricted Search behavior occurred in three locations. First, in March before the migration started, in the lagoons of San Ignacio and Ojo de Liebre where it was associated with the reproductive behavior of gray whales in the region this time of year (Rice and Wolman, 1971; Urbán et al., 2003). Second, in April south of Kodiak Island, a known feeding area for gray whales (Moore et al., 2007), and third in Chirikov Basin, a main feeding area for the ENP gray whales (Moore et al., 2003; Highsmith et al., 2006; Jones and Swartz, 2009).

Although aerial survey data over the past 20 years suggests a decline in the abundance of gray whales feeding in the Chirikov Basin in summer (Moore et al., 2003) it was the only Bering Sea feeding area used by this whale between May 24 and July 11. Other foraging areas in the Bering Sea known to occur along the Chukotka Peninsula, Russia, were not used

(Heide-Jørgensen et al., 2012). Interestingly, no other ARS behavior occurred during migration when passing other known gray whale feeding areas, such as Puget Sound, Washington (Weitkamp et al., 1992), and Clayoquot Sound, British Columbia (Darling et al., 1998; Dunham and Duffus, 2001, 2002).

The information provided by this tagged whale documents a coastal migratory route, speed, and timing of a single whales' migration, which is consistent with previous studies and constitutes the first complete northbound migration of an eastern gray whale reported to date.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The animal study was reviewed and approved by Secretaría del Medio Ambiente y Recursos Naturales.

AUTHOR CONTRIBUTIONS

JU: conceptualization. EJ-L: formal analysis. JU, LV-G, and HG: funding acquisition. LV-G: project administration. JU and EJ-L: writing—original draft. JU, EJ-L, HG, and LV-G: writing—review

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2021.619290/full#supplementary-material>

Supplementary Figure 1 | (A) Distance calculates from locations to coastline based on Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) from NOAA. **(B)** Deep values extracted for each location based on GEBCO 2019 Gridded Bathymetry.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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