A note on using satellite telemetry to document the use of San Ignacio Lagoon by gray whales (*Eschrichtius robustus*) during their reproductive season

Bruce R. Mate*, Barbara A. Lagerquist* And Jorge Urban-Ramirez+

Contact e-mail: bruce.mate@oregonstate.edu

ABSTRACT

In February 1996, 12 gray whales (*Eschrichtius robustus*), consisting of six animals without calves and six females with calves, were instrumented with Argos satellite-monitored radio tags in San Ignacio Lagoon, Baja California Sur, Mexico. San Ignacio is one of only three major breeding and calving lagoons located along the Pacific Baja Coast. Tracking periods ranged from 1.5 to 20.8 days. Mothers stayed in the lagoon longer than animals without calves and made repeated excursions to and from the lagoon. The experiment took place at a time of year when the number of animals without calves usually declines, which likely influenced the residence time of these animals in the lagoon. The question of residence time and turnover of both animals with and without calves is important in establishing how many whales actually use the lagoon during the winter reproductive season.

KEYWORDS: GRAY WHALE; SATELLITE TAGGING; TELEMETRY; MOVEMENTS; DISTRIBUTION; BREEDING GROUNDS

INTRODUCTION

The Eastern stock of gray whales migrates to winter areas on the Pacific coast of Baja California, Mexico from summer feeding grounds in the northern Bering, Chukchi and Beaufort Seas, and to a lesser extent from waters off Southeast Alaska, British Columbia, Washington, Oregon and northern California (e.g. Rice and Wolman, 1971; Swartz, 1986). Three lagoons of Baja California have long been recognised as important breeding and calving areas for gray whales: Laguna Ojo de Liebre (Scammon's Lagoon); San Ignacio Lagoon; and Magdalena Bay (Scammon, 1874).

San Ignacio Lagoon (26°43'N, 113°16'W) is the smallest of these (Fig. 1). It was declared a whale refuge by Presidential decree in late 1970 and became part of the Vizcaino Biosphere Reserve in 1988. The northern two-thirds (upper and middle) of the lagoon are set aside as a sanctuary. Tourist and fishing activities are prohibited in the sanctuary during the breeding and calving season. The lower third of the lagoon, however, is a popular and regulated whalewatching destination. San Ignacio Lagoon was also the site of a proposed salt-production facility. The effects of such activities on gray whales in the lagoon were unknown (Urbán-R *et al.*, 1997) and part of the motivation for this study.

Previous aerial (Gilmore, 1960; Hubbs and Hubbs, 1967; Gard, 1974; 1978; Rice *et al.*, 1981; Mizroch *et al.*, 1984) and boat surveys (Swartz and Jones, 1980; 1981; Jones and Swartz, 1984) of San Ignacio Lagoon suggest the population of gray whales at any one time is a fraction of the total population. Data from recent boat surveys revealed a maximum combined count (both animals with and without calves) of 207 gray whales in the lagoon in the first week of March 1996 (Urbán-R *et al.*, 1997). The population estimate for that same winter was 22,263 (CV = 0.0925) whales (Hobbs *et al.*, 1996). Evidence from photographic identification studies, shore-based observations of the main entry channel to the lagoon and radio-tagging studies suggests a considerable turnover in the lagoon population (Jones and Swartz, 1984; Mate and Harvey, 1984). Photographic evidence has also confirmed that two whales moved from one breeding lagoon to another in the same season (Jones and Swartz, 1984). The extent of this type of interchange between lagoons is unknown. Without a good understanding of the amount of exchange and the turnover rates, it is impossible to accurately estimate the number of animals using a particular lagoon (Mate and Harvey, 1984).

The purpose of this study was to examine the movements of gray whales tagged in San Ignacio Lagoon, to try to obtain some insight into lagoon residency, the extent of movements in and out of the lagoon, and interchange between other breeding lagoons.

METHODS

From 8 to 16 February 1996, 12 Argos (satellite-monitored) radio tags were attached to gray whales in San Ignacio Lagoon. Two tag types were used. One type consisted of a *Telonics* ST-10 Argos transmitter in a cylindrical housing identical to that used on humpback (Mate *et al.*, 1998) and blue whales (Mate *et al.*, 1999). These tags (17cm long by 2.5cm in diameter) provided the location information discussed here as well as percentage of time the whale spent at the surface (not discussed). The other tag was a *Telonics* ST-6 Argos transmitter with a Wildlife Computers controller board in a larger cylinder identical to that used on blue whales (Mate *et al.*, 1999). In addition to the location information, these larger tags (19cm long by 5cm in

* *Oregon State University, Fisheries & Wildlife, Coastal Oregon Marine Experiment Station, Hatfield Marine Science Center, Newport, Oregon 97365, USA.*

+ *Departamento de Biologia Marina, Universidad Autónoma de Baja California Sur, La Paz, B.C.S., México.*

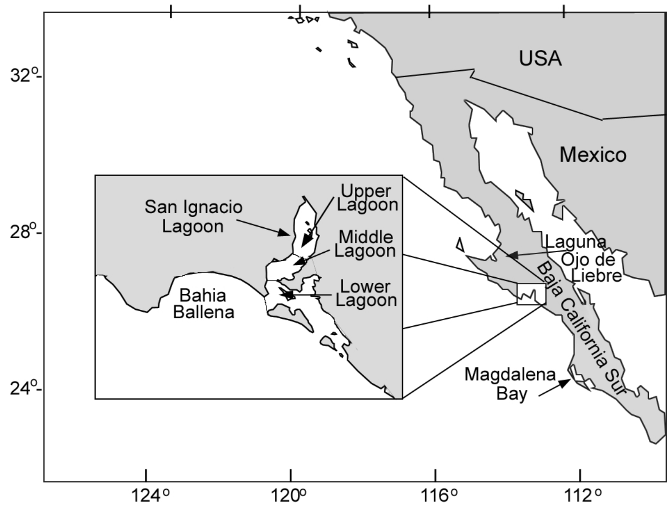

Fig. 1. Study area of the 1996 gray whale tagging effort in San Ignacio Lagoon.

diameter) transmitted data summarising the whale's dive habits (not presented in this manuscript). Both types were attached to the whale's back with two subdermal anchors, each consisting of a stainless steel rod with a cutting tip and backward-facing barbs to hold them in the blubber layer. Tags were applied close to the mid-dorsum (1.5-6m behind the blowhole) with a *Barnett* compound crossbow (68kg). Whales were approached from behind and to one side at a vessel speed similar or slower than the whale's speed of travel. Once within deployment range (2-6m), vessel speed was increased to slightly greater than the whale's so as to catch up and position the tag in the desired location. In cases where whales were 'resting' at the surface, the boat approached at just above idle with as little change in engine pitch as possible. The tags transmitted every 10s ($n = 2$) or 20s ($n = 10$) when the tag was above water during alternate 6h periods (0900 to 1500, and 2100 to 0300 GMT).

The tags were monitored by Argos Data Collection and Location Service receivers on two NOAA TIROS-N weather satellites in sun-synchronous polar orbits. At the latitude of San Ignacio Lagoon, each satellite passes over the region 7–8 times/day. With the programmed duty cycle (12h/d), it was possible to acquire data from up to 10 orbits/d. Surfacing was determined when the tag's conductivity switch was above the surface of the water.

Locations were calculated by Argos from Doppler shift data when multiple messages were received during the 7 to 16 minutes of a satellite's passage overhead. It was not possible to determine the accuracy of locations when less than three messages were acquired within a single orbit (location quality ≤ 0). Screening criteria were used to edit these locations by allowing an 11.5km error radius around them (Mate *et al.*, 1997). Distances and speeds were then calculated between edited locations. Locations were eliminated if speeds between adjacent locations were > 15km/h for < 1h, > 10km/h for > 1h, or were located on land > 11.5km from the nearest shoreline. Overall speeds were calculated by dividing a whale's total distance travelled between locations by the total time between tagging location and last location received. As such, these speeds represent minimums. It is important to emphasise that the lines connecting locations do not imply the route taken by the whale, but merely the chronological order of locations.

Given the error radius, it was impossible to determine whether locations of < 0 quality within 11.5km of the lagoon entrance were actually inside or outside the lagoon. Therefore, only locations of quality > 0 (good quality) were used for inside vs. outside lagoon comparisons.

RESULTS

Six females with calves, hereafter referred to as 'mothers' (whales M-1 through M-6; estimated length $\overline{X} = 12.4$m), and six other whales (estimated length $\overline{X} = 11.5$m), hereafter referred to as 'singles' (whales S-1 through S-6; Table 1) were tagged. The sex of only one of the six singles could be positively determined. The single whales consisted of two solitary whales, one whale from each of three different pairs, and a male in a mating group of 4–5 individuals pursuing a mother with a calf. Since it was late in the calving season, it is extremely unlikely that any of the single whales became mothers.

Table 1

Tag identity, tagging date, duration of operation, sex, estimated size and group composition of 12 gray whales instrumented with Argos satellite-monitored radio tags in San Ignacio Lagoon, Baja California Sur, Mexico, February to March 1996.

Tag #	Tagging date	Days of attachment	Sex	Length (m)	Group composition
S-1	8 Feb 96	15.0	Unknown	10	Singleton
S-2	8 Feb 96	3.5	Male	13	Three escorts with mother/calf
S-3	10 Feb 96	2.7	Unknown	11	Singleton
S-4	11 Feb 96	8.1	Unknown	12	Two adults
M-1	13 Feb 96	2.3	Female	12.5	Mother with calf
M-2	13 Feb 96	20.8	Female	12	Mother with calf
M-3	13 Feb 96	1.4	Female	--	Mother with calf
S-5	14 Feb 96	3.1	Unknown	11	Two adults
S-6	14 Feb 96	1.5	Unknown	12	Two adults
M-4	14 Feb 96	12.7	Female	12.5	Mother with calf
M-5	14 Feb 96	1.4	Female	13	Mother with calf
M-6	16 Feb 96	9.1	Female	12	Mother with calf

Whales exhibited no strong reactions to the tagging process, and the mild reactions that were observed were short-lived. The majority consisted of an exaggerated fluke beat upon tagging ($n = 7$). In four other cases the animals dived quickly upon tagging. One whale exhibited no reaction to the tagging process.

There was no significant difference in mean tracking period between singles ($\overline{X} = 5.6 + 5.11$d) and mothers ($\overline{X} = 9.1 + 8.17$d; t-test $p = 0.41$). Locations were received for 11 of the 12 tagged whales (6 singles and 5 mothers; Table 2). The total number of locations received per day did not differ significantly between singles ($\overline{X} = 2.9 + 2.1$) and mothers ($\overline{X} = 2.3 + 1.7$; t-test $p = 0.65$). Sample sizes were too small to warrant statistical comparisons of tracking periods or number of locations between the two tag types (only two large tags), however the values for the larger tags were within the ranges for the smaller tags.

The fastest overall speed (5.1km/h, 123km/d) was obtained for a single whale (S-1) that began its northward migration two days after tagging (Mate and Urban-Ramirez, 2003). One other single whale (S-4) also began its northward migration, but did not provide enough locations to allow us to determine exactly when it left the lagoon area. Its first location after tagging was five days later (16 Feb) and 399km northwest (minimum of 3.5km/h, 83km/d). Whales S-1, S-4 and S-5 (4.1km/h, 99km.d), moving north beyond Bahía Ballena, had the top three highest speeds for all whales.

Table 2

Location data derived from satellite-monitored radio tags on single and mother gray whales in and around San Ignacio Lagoon, Baja California Sur, Mexico, February to March 1996.

Whale ID (tag type)	Number of locations[a]	Total days tracked	Locations[a] per day	Distance (km)	Days from first to last location[a]	Speed (km/day)	Number of locations of >0 quality
Singles							
S-1 (ST10)	37	15.0	2.5	1779	14.5	123	5
S-2 (ST10)	6	3.5	1.7	52	3.5	15	1
S-3 (ST10)	6	2.7	2.2	68	2.7	25	0
S-4 (ST10)	3	8.1	0.4	537	6.5	83	0
S-5 (ST6)	20	3.1	6.4	306	3.1	99	3
S-6 (ST6)	6	1.5	4.0	77	1.5	51	1
Mean (SD)	13 (13.2)	5.6 (5.11)	2.9 (2.11)	470 (668.7)	5.3 (4.80)	66 (42.6)	1.7 (2.0)
Mothers							
M-1 (ST10)	0	2.3[c]	--	--	--	--	--
M-2 (ST10)	78	20.8	3.8	642	20.8	31	23
M-3 (ST10)	3	1.4	2.1	68	0.9	76	0
M-4 (ST10)	42	12.7	3.3	521	12.7	41	2
M-5 (ST10)[b]	1	1.5	0.7	7	1.2	6	0
M-6 (ST10)[b]	38	9.1	4.2	287	8.8	33	10
Mean (SD)	32 (31.8)	9.1 (8.17)	2.8 (1.42)	305 (276.4)	8.9 (8.36)	37 (25.2)	7.0 (9.8)

[a]Locations of any quality that met our editing criteria. [b]These two tags had a 10s repetition rate, all others had a 20s repetition rate. [c]Transmissions were received for 2.3 days, but no locations were provided.

Only seven whales (4 singles and 3 mothers) had locations of qualities > 0 (Figs 2-3). The median percentage of total locations that were of good quality did not differ significantly between singles (15.8%) and mothers (26.0%; Mann-Whitney W-test $p = 0.59$). These seven whales were the only animals considered for inside vs outside lagoon comparisons, however samples sizes were too small to warrant statistical comparisons.

Two single whales provided good quality locations for longer than two days: S-1 (Mate and Urban-Ramirez, 2003; Fig. 2a) and S-5 (Fig. 2c). Whale S-1 was tagged just outside the mouth of the lagoon and did not enter the lagoon, beginning its migration north two days after tagging (10 Feb). Whale S-5 left the lagoon within 17.8h after tagging (15 Feb) and did not re-enter. The other two single whales did not leave the lagoon, but their tracking periods (between good quality locations) were extremely short (2.6h and 29.1h, respectively, Figs 2b, 2c), with only one good quality post-tagging location each. Both of these latter locations were in the lower portion of the lagoon, near the lagoon entrance.

All three mothers with location qualities > 0 made at least one excursion to and from the lagoon during their tracking periods, travelling into adjacent Bahía Ballena (Fig. 3). When only one location was received on either end of an excursion (one location outside the lagoon followed by one location inside and so on), the time spent inside vs outside the lagoon during the excursion could not be accurately determined. This was the case for M-4 (Fig. 3b), for which only two good post-tagging locations were received. Whale M-4 left the lagoon sometime in the 76.1h following tagging, and then re-entered the lagoon sometime in the next seven days. Her last location was in the middle portion of the lagoon (on 25 Feb).

When two or more successive locations were inside or outside the lagoon, the minimum time spent in that area could be determined. Whale M-2 stayed in the lagoon for 2.3 days after tagging, followed by a departure from the lagoon sometime in the next 1.3 days. In the next 3.7 days she re-entered and left the lagoon again, after which she spent a minimum of 7.7h outside the lagoon, before re-entering for a third time. The remainder of M-2's tracking period (between good locations) was spent in the lagoon (17.6d, last location on 2 Mar). Thirteen percent of M-2's good locations were spent in the upper portion of the lagoon, 35% in the middle portion, 39% in the lower portion and 13% outside the lagoon.

Whale M-6 left the lagoon only once, following a 3.3 day period in the lagoon after tagging. This excursion took place sometime in the next 18.8h. Whale M-6 then re-entered the lagoon sometime in the next 4.8h, where she remained for the duration of her tracking period (4.0d, last location on 25 Feb). Thirty percent of her good quality locations were in the middle portion of the lagoon, 60% in the lower and 10% outside the lagoon.

DISCUSSION

This preliminary study demonstrates the feasibility of monitoring gray whale movements by satellite, and provides some confirmation to previous studies' findings that single whales depart from the lagoon before females with calves (mothers). Jones and Swartz (1984) found single whales departing from San Ignacio Lagoon approximately one month before mother-calf pairs. They also report a mean residence time of 11 weeks for singles with the mean day of residency ranging from 1-16 Feb. The study here does not accurately address the issue of residence time, as tagging was not done at the beginning of the season and it was not known how long whales had already been in the lagoon. The two single whales that began their northward migrations left the lagoon area (including Bahía Ballena) within 2-5 days of tagging (tagged 8 and 11 Feb).

Overall speeds were highest for single whales moving north beyond the lagoon area. This may reflect actual differences in speed of travel, but more likely reflects the nature of the speed calculation. Total distance between locations is used to calculate overall speed. For animals moving in a more or less straight line, the measured distance more accurately reflects true distances covered, and thus travel speeds. For animals moving in a non-linear fashion, as

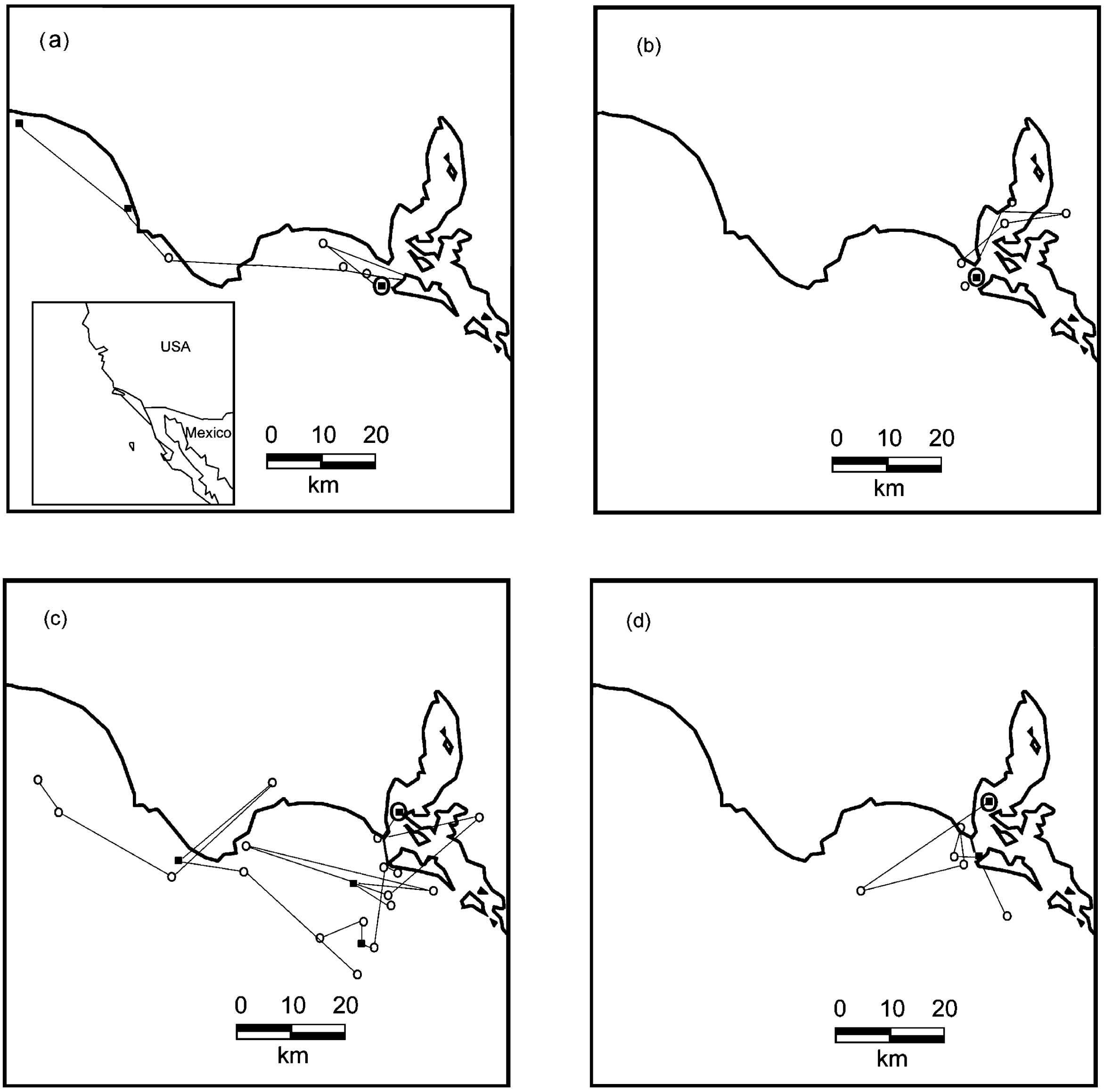

Fig. 2. Satellite-acquired locations of 4 single gray whales tagged in San Ignacio Lagoon, Feb 1996: (a) whale S-1, showing inset of full migration (details in Mate and Urban-Ramirez, 2003); (b) whale S-2; (c) whale S-5; and (d) whale S-6. Locations for whales S-3 and S-4 are not depicted as too few locations passed editing criteria. ⊙ represents the tagging location for each whale. ○ represents locations of $\leqslant 0$ quality that met our editing criteria. □ represents locations of >0 quality.

with clustered movements in a small area, total distance between locations is underestimated, as are speeds.

The distribution pattern was quite different between single whales and mothers, with 100% of locations for single whales being either in the lower portion of the lagoon or outside the lagoon (not including the two that began their northward migration), but only 57% of locations for mothers being in these same areas. In their surveys within San Ignacio Lagoon, Jones and Swartz (1984) noted a preference by single whales for the lower lagoon region, and also use of the entrance to the lagoon. A preference by single animals for lagoon entrances has also been reported for Laguna Ojo de Liebre and Magdalena Bay (Gilmore, 1960). The predominant activity in these areas is courtship and mating (Gilmore, 1960; Samaras, 1974; Norris *et al.*, 1983; Jones and Swartz, 1984). Jones and Swartz (1984) have suggested that the deeper waters of the lower lagoon (2-4 times deeper than the middle and upper lagoon) may be more conducive to sexual behaviour. Several factors may contribute to these activities in the lower lagoon, including an increase in the likelihood of encountering other single whales moving in and out of the lagoon and mothers with calves spending a greater percentage of their time farther up lagoon, possibly to avoid mating. While mothers may leave the lagoon briefly, the activities of tagged whales (mothers) were most concentrated in the lower two-thirds of the lagoon, which is consistent with survey results from the same time of year (Jones and Swartz, 1984). Jones and Swartz (1984) felt that mothers with calves may actively avoid courting groups of whales due to the disruptive and potentially harmful nature of mating aggregations. Thus their use of the more inner portions of the lagoon while singles are still around is not unexpected. The use of the entrance area and adjacent Bahía Ballena by single whales, as well as the back and forth movement of mothers, emphasises the importance of surveying both inside and outside the lagoon when determining abundance.

While these results provide some minimum residence time information and lagoon utilisation by individual gray whales, they must be treated with caution. The sample sizes are small, and not representative of the whole population. Tagging mid-season biases the estimates of residence times

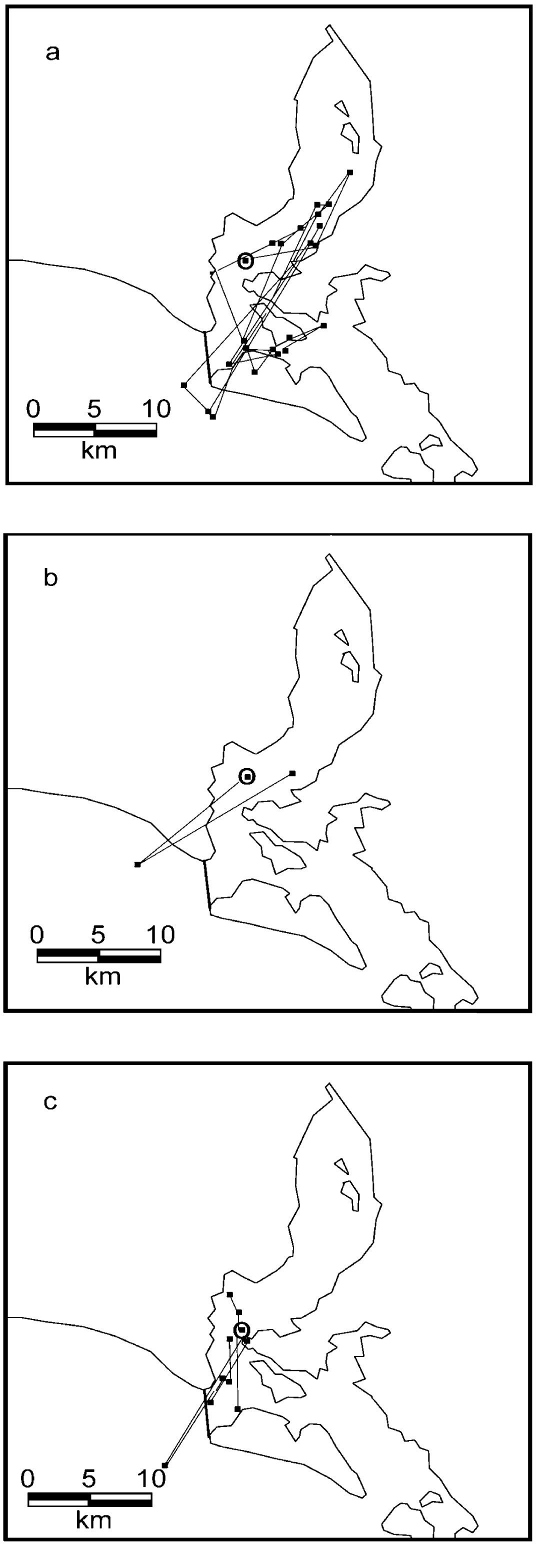

Fig. 3. Satellite-acquired locations of 3 mother/calf gray whale pairs tagged in San Ignacio Lagoon, Feb 1996: (a) whale M-2; (b) whale M-4 and (c) whale M-6. Locations for whales M-3 and M-5 are not depicted as too few locations passed editing criteria. ⊙ represents the tagging location for each whale. Only locations of > 0 quality are shown.

downward, as many whales may have been there for some time already and others would soon be leaving the lagoon. Also, tag attachment was quite short, again biasing residence time downward. Finally, the conservative criteria of only using good quality locations for examining movement into or out of the lagoon may have resulted in an underestimate of these movements. A good example of this is the single whale S-6 (Fig. 2d). Only one good post-tagging location was received, suggesting the animal stayed in the lagoon following tagging. If lesser quality locations were considered, there would be little argument that this animal had indeed left the lagoon, as four lesser quality locations in a row were outside the lagoon entrance, one of which was further from the entrance than our 11.5km error radius.

Future studies would benefit from increasing the transmission capability of all tags from 20s to 10s, which would result in more messages received per satellite pass, contributing to higher numbers of good quality locations. Benefits would also be gained by tagging a larger number of whales, earlier in the reproductive season and with longer-lasting tags. The latter can be achieved with the use of smaller, implantable tags, reducing their vulnerability to hydrodynamic drag or being scraped off during courtship and normal intimate mother/calf behaviour. Longer-term tracking could reveal the extent to which whales use other reproductive and/or offshore areas during the same winter. Tagging earlier in the reproductive season would provide better estimates of the duration of lagoon residency and other seasonal movements. It may also be important to tag animals in offshore areas, as the majority of gray whales (other than cow/calf pairs) may spend the winter outside lagoons (Mizroch *et al.*, 1984).

Even with such short periods of attachment, we believe satellite-monitored tags provide an improvement in range and confidence over conventional VHF/HF tags (Mate and Harvey, 1984) in resolving questions of whale movement, both within lagoon reproductive areas and offshore.

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