The influence of whalewatching on the behaviour of migrating gray whales (*Eschrichtius robustus*) in Todos Santos Bay and surrounding waters, Baja California, Mexico

Gisela Heckel*, Stephen B. Reilly**, James L. Sumich+ and Ileana Espejel++

Contact e-mail: gheckel@telnor.net

ABSTRACT

This study investigated the influence of whalewatching boats on the behaviour of gray whales on their migratory route in Todos Santos Bay, near the port of Ensenada, Baja California, Mexico. The objectives were: (1) to compare the swimming direction and velocity of whales in the presence and absence of whalewatching vessels, and when other boats were fishing, cruising or drifting; and (2) to contribute scientific data to the improvement of whalewatching regulations for Todos Santos Bay and surrounding waters. During the winters of 1998 and 1999, theodolite tracking was undertaken from a lighthouse tower located on northern Todos Santos Island. During both years, the migration corridor was about 2.5km wide at the Todos Santos Islands; this is relatively narrow compared to other shore stations along the northern coast (USA). Sightings were separated into northbound or southbound migration routes and the variability of whale swimming direction was analysed by circular statistics. During the southbound migration, whale swimming direction was not different in the presence or absence of whalewatching vessels and other boats. This variable, however, was statistically different during the northbound migration both with whalewatching vessels ($p = 0.007$) and with other boats ($p = 0.02$). Whale swimming velocity showed significant differences without boats and with whalewatching boats during both migrations (northbound, $p = 0.04$; southbound, $p < 0.001$). Analysis of velocity in the absence and presence of other boats did not yield significant differences for either of the migrations. In addition, a head-on approach by whalewatching boats changed the whales' swimming direction ($p = 0.05$) and velocity ($p = 0.015$) significantly when compared with an approach towards the rear or flanks. Although Mexican whalewatching law is explicit concerning manoeuvres around whale groups, an additional suggestion is made here to prevent unintentional head-on approaches.

KEYWORDS: WHALEWATCHING; GRAY WHALE; MIGRATION; BEHAVIOUR; SHORT-TERM CHANGE; MEXICO; PACIFIC

INTRODUCTION

The tremendous growth of whalewatching around the world during the last ten years has caused concern about its potential impacts on cetaceans (e.g. IFAW, 1995; IWC, 1995). Eastern Pacific gray whales (*Eschrichtius robustus*) move close to shore during their annual migration from Alaska, USA, to Baja California Sur, Mexico, which has enabled their observation from vantage points on land and boats for many years (Wilke and Fiscus, 1961). Some accounts of the effects of vessels on migrating gray whales have been reported (MBC Applied Environmental Sciences, 1989; Moore and Clarke, In Press), although no systematic surveys to evaluate the significance of this had been attempted prior to this investigation.

Twelve years ago, whalewatching occurred only occasionally in Ensenada (Mexico), e.g. when private groups organised independent one-day trips. From 1989 onwards, the local Science Museum arranged regular whalewatching tours onboard sport fishing vessels. For the owners of the companies and boats, this substitute activity turned out to be attractive because in winter, sport fishing declined considerably (Leyva, pers. comm.[1]), as in Oregon, USA (Manfredo *et al.*, 1988). The growing demand for whalewatching in Ensenada has created competition and provided an incentive to increase the activity.

[1] Claudia Leyva, Facultad de Ciencias, Universidad Autónoma de Baja California, Km 103 Carretera Tijuana-Ensenada, Ensenada, Mexico.

At present, the Mexican Official Law NOM-131-ECOL-1998 (SEMARNAP, 2000) regulates whalewatching on the gray whale's breeding grounds (i.e. the lagoons in Baja California Sur, Mexico) and the migratory route in Mexican waters, such as Todos Santos Bay (Fig. 1). However, specific regulations need to be established (based on scientific research) for each whalewatching area due to differences in the whales' behaviour (reproduction *vs* migration), habitat (enclosed lagoons and open waters) and the whalewatching industries in each area (Reyna and Alcántara, 2000).

This study investigated the influence of whalewatching boats on the behaviour of gray whales on their migratory route in Todos Santos Bay, Mexico, during the winters of 1998 and 1999. The objectives were: (1) to compare the swimming direction and velocity of whales in the presence and absence of whalewatching vessels, and when other boats were fishing, cruising or drifting; and (2) to contribute scientific data to the improvement of whalewatching regulations specific for Todos Santos Bay and surrounding waters.

METHODS

Field data collection and data treatment

Todos Santos Bay is on the northwestern coast of Mexico (100km south of San Diego, USA). The port of Ensenada is located in the centre of the bay and two small volcanic

* *Facultad de Ciencias Marinas, Universidad Autónoma de Baja California, Plácido Mata 2309 Depto. D-5, Condominio Las Fincas, 22830 Ensenada, Baja California, Mexico.*
** *Southwest Fisheries Science Centre, 8604 La Jolla Shores Drive, La Jolla, California, 92038-0271, USA.*
+ *Grossmont College, El Cajon, California 92020, USA.*
++ *Facultad de Ciencias, Universidad Autónoma de Baja California, Km 103 Carretera Tijuana-Ensenada, 22800 Ensenada, Baja California, Mexico.*

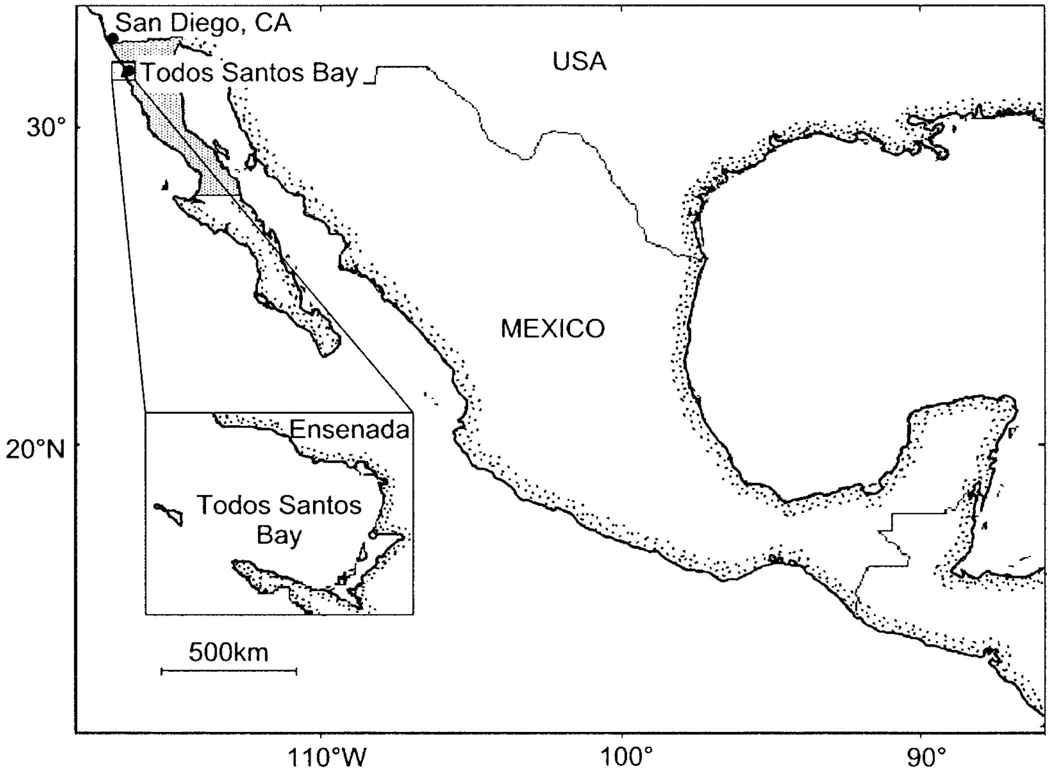

Fig. 1. Map of Mexico and position of the study area: Todos Santos Bay, Baja California, Mexico.

islands mark its entrance (Fig. 2). From January-March 1998 and 1999, land-based observations were conducted from a lighthouse tower located on northern Todos Santos Island (31°48'43'N, 116°48'28'W). The site was selected because whales are frequently encountered on the commercial whalewatching route in this area (Fig. 2) and the altitude of the tower (51.64m above the mean lowest low-water level) provided an excellent overview.

The working team (two observers) stayed on the island from Friday to Tuesday each week (weather permitting) since whalewatching tours occurred mainly from Friday to Sunday. Vessel traffic was almost always absent in Todos Santos Bay on Mondays. Sightings[2] made on Mondays and when no boats were in view (approximately 20km with good visibility) were used as independent controls, where no influence from vessels on whales' behaviour was assumed. Two observers watched for the longest time possible each day, according to light and weather conditions. Watches started at 0800hrs and usually finished around 1300hrs, when visibility became poor due to high winds (Beaufort sea state >3). Sightings were terminated when fog reduced visibility to less than 4km or the tracked whale group entered sun glare.

Vessel and whale movements were observed from the lighthouse platform. Once a whale group was detected, one of the observers tracked its movements with a *Topcon* DT102 electronic theodolite. The second observer used 7×50 binoculars and a stopwatch to record the start and finish time of the sighting (important for later calculation of swimming velocity) (IFAW, 1995). The second observer dictated data (angles, times and behaviour) into a microcassette recorder. Watching positions were not rotated to eliminate possible inter-observer discrepancies. At the end

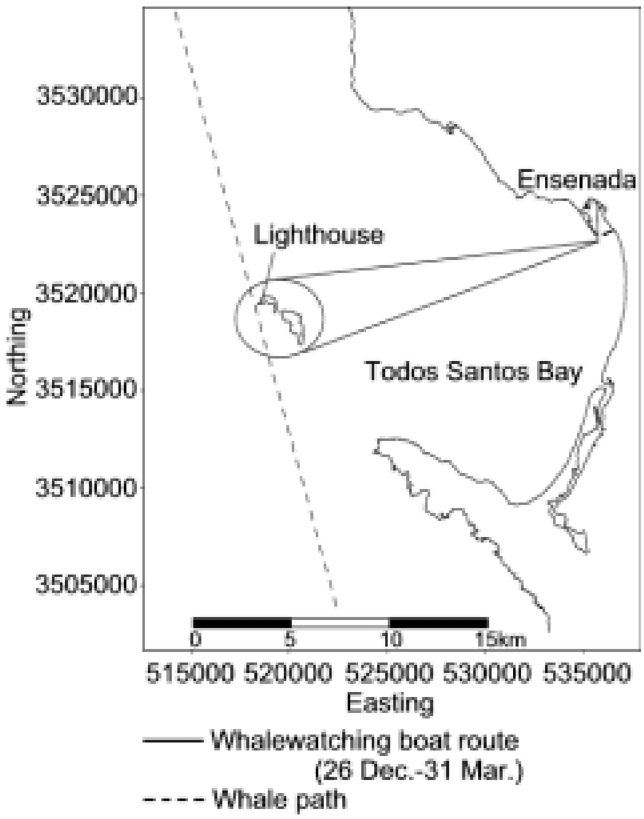

Fig. 2. Whalewatching boat route and location of the lighthouse on northern Todos Santos Island, the land-based observation platform in this study. Map coordinate systems are in Universal Transverse Mercator (UTM, thousand meters) projection. 'Easting' is equivalent to Longitude, 'Northing' is equivalent to Latitude (see 'Methods' for details).

[2] Sighting: Tracking of a single whale or whale group. Starting with the first sign of a whale (usually a blow, or part of whale body) and finishing 15 minutes after the last observation was made. Sightings (and not individual whales) were the basic sampling unit because behavioural observations of individuals within a group might be difficult to achieve. A group is an aggregation of whales where maximum distance between individuals is less than five body lengths (MBC Applied Environmental Sciences, 1989).

of each day, recordings were transferred onto check sheets. The data were later recorded in a computerised database (*Microsoft Access 97*).

The theodolite measured vertical and horizontal angles (in degrees from true north) from the platform to an object. The angles were transformed into *x, y* coordinates with T-Trak (an IBM-compatible computer program by Cipriano, 1990) and plotted on a map. The major source of error in location is an incorrect measurement of platform height (Würsig *et al.*, 1991). Therefore, the exact height of the lighthouse platform (51.64m) was determined following Würsig *et al.* (1991) by means of a topographic profile. Furthermore, calculations of *x, y* coordinates considered height change due to tidal water level fluctuations (observed water levels at a station in San Diego, USA; NOAA, 1999) and curvature of the Earth (Cipriano, 1990).

Measurements were taken of vertical and horizontal angles of whalewatching and other boats (fishing, cruising or drifting) when present with whales. These sightings were defined as 'with whalewatching boats' and 'with other boats'.

A number of possible confounding effects were considered in the data analyses (Reilly *et al.*, 1983; Sumich, 1983), although whale groups were not differentiated by sex and/or age composition (except adult/calf pairs). From the original dataset, sightings were categorised according to the following characteristics to minimise errors.

(1) Migration direction: all sightings were separated into southbound and northbound migrations. The first northbound swimming whales passed Ensenada by mid-February and moved at a slower speed than when they migrated south (Rice, 1965; MBC Applied Environmental Sciences, 1989).
(2) Group size: behaviour may differ if whales are in small or large groups. Groups with 1-4 whales were used because their swimming speed did not vary significantly (see Results).
(3) Visibility: because weather conditions affect the probability of detecting whales, only sightings with 'good' visibility or better (according to Reilly *et al.*, 1983) were included in the analysis.
(4) Quality of positional data: sightings were eliminated if a whale group was located less than three times (theodolite 'fixes').
(5) Adult/calf pairs: field work was terminated by the end of March (the end of the whalewatching season in Ensenada). This seems to coincide with the end of the northbound 'Phase A' migration, when almost no females with their calves are migrating (Herzing and Mate, 1984). Only a few adult/calf pairs were observed in this study and were eliminated from the analyses because of the small sample size and because their behaviour differs from that of other whale groups (MBC Applied Environmental Sciences, 1989).

Analytic methods

Mapping migration tracks

The migration tracks observed during this study were investigated to understand the migration path of gray whales along the coast of Ensenada, as well as possible changes due to whale-boat interactions.

For each sighting, locations ('fixes') of single whales, whale groups and boats (objects) were plotted on a digitised map of the study area (Instituto Nacional de Estadistica, Geografía e Informática, 1982) with computer drawing tool *AutoCADR13*, using the Universal Transverse Mercator (UTM) projection[3] (Greenhood, 1964). Thus, the *x, y* coordinates for each object location were transformed into UTM, based on the lighthouse location (31°48'43'N, 116°48'28'W). Consequently, object locations were plotted on a map and swimming directions are shown as straight lines of true compass direction (tracks). Six maps were generated: sightings during the northbound and southbound migration 'without boats' (controls), 'with whalewatching boats' and 'with other boats'.

Swimming direction

Direction was calculated with the computer program T-Trak (Cipriano, 1990). Direction is a 'circular variable' - a special form of interval scale that requires special statistical procedures (Batschelet, 1981; Zar, 1999)[4]. Calculations were made for $\bar{\phi}_i$ (mean angle) and r_i (mean vector length) for each sighting, and then for the grand mean ($\bar{\phi}$ and r) for sightings categorised as 'without boats', 'with whalewatching boats' and 'with other boats' (Batschelet, 1981; Zar, 1999). Parametric tests could not be used to compare the samples[5] because the necessary assumptions were not fulfilled.

Mardia's non-parametric procedure was applied to compare pairs of samples 'without boats' to 'with whalewatching boats' and 'without boats' to 'with other boats' (Batschelet, 1981). Sightings without boats were tested for differences between years 1998 and 1999. Differences in the mean angle were examined using the non-parametric Mardia-Watson-Wheeler test (Batschelet, 1981).

The non-parametric test of dispersion was also applied for circular data to test for differences in the angular deviation (*s*) of two samples (Batschelet, 1981). Each sighting's angular deviation is expressed here by the angular distance ($\bar{\phi}_i - \bar{\phi}$). These were ranked for both samples. The largest sum of the two samples was compared with the Mann-Whitney *U* test, although the normal approximation was used when sample sizes were large ($n_k > 40$; Zar, 1999).

Swimming velocity

Velocity (v_{ij}) was calculated with T-Trak, based on the observed distance and time between successive whale locations during a sighting. Each sighting's mean swimming velocity was the response variable ($\bar{v}_i$), and sightings were categorised as for direction.

Assumptions for parametric tests were not met, therefore the non-parametric Mann-Whitney test for two independent samples (Neave and Worthingon, 1988) was used to search for differences between mean swimming velocity 'without boats' 'with whalewatching' or 'other boats' ($\bar{v}$).

The parametric variance ratio test was used for detecting differences between sample dispersion (variance, s^2). The variances of all sightings (s^2_i) were transformed into their natural logarithms to meet the basic assumption of normal distribution (Zar, 1999).

One element was investigated that might have elicited apparent whale reactions. Sightings with whalewatching boats during the northbound migration were divided into head-on approach (45° to the left or right from the whale

[3] UTM is the usual projection in topographic maps. Unit measurement is in meters. INEGI uses the Clarke 1866 spheroid and the North American 1927 datum (sea level reference) for Mexico. The UTM projection divides the Earth into 60 zones, each six degrees wide in longitude. Mexico is in zone 11.
[4] Notation of circular statistics follows Batschelet (1981).
[5] Sample: In this study, group of sightings categorised as 'without boats', 'with whalewatching boats' and 'with other boats'.

group's perspective) and approach towards the rear or flanks. Classification into these two groups was accomplished by visual examination of whale and boats' tracks during each sighting. Direction was analysed with the non-parametric test of dispersion and velocity was analysed with the variance ratio test.

RESULTS

During 55 days of field work, 284 hours were spent on the lighthouse platform (average 5.03hrs/day, range 1.17-9.48hrs/day), and whales and/or ships were tracked for 165 hours (Table 1). The effort was lower (and so were whalewatching trips) in 1998 (19 days in the field, compared to 36 in 1999) because of frequent storms during that year's El Niño event. A total of 298 sightings was obtained; 182 were selected for the analyses (see 'Methods' for selection criteria). For sightings with less than three whale locations, the rejection rate was higher for sightings with boats (18%) than for sightings without boats (15%). This might be due to observer difficulty in locating whales and boats alternately and as rapidly as possible, and therefore whale groups could have been lost. In addition, whale reaction to boats might cause them to be located less often than when they were undisturbed. The rejection of some sightings with boats might have reduced the apparent effects of whalewatching. In addition, the swimming velocity of different group sizes (1-7 whales/group) was compared. Only groups with 1-4 whales showed no significant differences (southbound migration: $n = 61$, Kruskal-Wallis $H = 5.19$, $p = 0.16$; northbound migration: $n = 55$, $H = 5.15$, $p = 0.16$) and were included in the analyses.

Table 1
Observation effort from January to March of 1998 and 1999 on northern Todos Santos Island, Baja California, Mexico.

Year	Days	Effort (hours)	No. of sightings	Sightings used in analyses	Observation efficiency
1998	19	102.8	107	51	48%
1999	36	181.3	190	131	69%
Total	55	284.1	297	182	61%

Migration tracks

South- and northbound migrating whales were clearly distinguished by their general swimming direction. During the southbound migration (January to mid-February), tracks spread north of the islands in a corridor *ca* 2.5km wide, then tended to concentrate to *ca* 1.2km at the northern island and expanded again when passing along the southern island (Fig. 3a). The general direction of the tracks tended to change from southwest to south and then southeast; minimum distance from shore changed from 0.25km at the northern island to 1km at the southern island (Fig. 3a).

During the northbound migration whale tracks showed a more dispersed and less directed pattern (Fig. 3b). The navigation corridor was about 1.9km wide at the southern island, reduced to approximately 0.7km at the northern island and expanded to about 1.5km after passing the islands. The general swimming direction was northwesterly, although a few tracks showed departures from this. Whales tended to swim closer to shore (minimum distance < 0.5km) than during the southbound migration. In addition, nursing and resting were observed less than 200m (depth < 20m) from the northern island's shore on 12 and 19 March 1999, respectively.

Whale tracks were also plotted when whalewatching boats were following the groups (Figs 3c and 3d). Tracks seemed to follow the general pattern without boats, although sample sizes differed (southbound: $n = 50$ without boats, $n = 11$ with whalewatching boats; northbound: $n = 45$ without boats, $n = 28$ with whalewatching boats).

Whale tracks with other boats (fishing, cruising or drifting) during the southbound migration (Fig. 3e) were similar to tracks without boats. During the northbound migration (Fig. 3f), however, several whale groups in the presence of other boats did not swim in the usual northwesterly direction, but northeasterly or to the west.

Swimming direction

More variable swimming directions were observed for whales (without boats) during the northbound than during the southbound migration (Figs 3a and 3b). The angular deviation (*s*) during the northbound (21°15') and during the southbound migration (14°17') proved to be significantly different ($Z = 5.30$, $p < 0.001$, $n_1 = 50$, $n_2 = 45$).

The comparison of mean whale swimming direction ($\bar{\phi}$) between pairs of samples (1998 and 1999 without boats, 'without boats' to 'with whalewatching boats', 'without boats' to 'with other boats') in either migration showed no significant differences. Therefore, the angular deviation (*s*) was used to detect possible changes of swimming direction during a sighting (Tables 2 and 3).

Sightings without boats were not statistically different in *s* between field seasons 1998 and 1999, in either migration (southbound: $U = 271$, $p = 0.34$, $n_1 = 14$, $n_2 = 36$; northbound: $U = 185$, $p = 0.39$, $n_1 = 10$, $n_2 = 35$). Hence, sightings without boats in both years were combined to compare them with sightings with whalewatching boats (Table 2). During the southbound migration there were no significant differences in swimming direction angular deviation between whale groups without boats and with whalewatching boats ($p = 0.16$). In contrast, during the northbound migration, the difference was statistically significant ($p = 0.007$, Table 2).

Swimming direction angular deviation without boats was also compared with other boats (fishing, cruising or drifting, Table 3) and was not statistically different during the southbound migration in this study ($p = 0.14$). However, during the northbound migration the difference was significant ($p = 0.02$).

Swimming velocity

A significant difference in mean velocity (without boats) was detected between southbound ($\bar{v} = 1.95$m/s) and northbound (1.39m/s) whales during 1999[6] (Mann-Whitney $U = 1{,}127$, $Z = 5.72$, $p < 0.001$, $n_1 = 36$, $n_2 = 35$). The variability of swimming velocity (variance, s^2_{ln}), however, was not different (southbound: 0.062; northbound: 0.057; $F = 1.14$, $p = 0.35$, $n_1 = 36$, $n_2 = 35$).

Mean swimming velocity seemed to increase in the presence of whalewatching boats during both the southbound and the northbound migration, and appeared to decrease in the presence of other boats. None of these differences was significant. Therefore, the variance was used to search for possible changes in swimming velocity during a sighting (Tables 4 and 5).

Velocity variance during the southbound migration showed no significant differences between 1998 and 1999 ($F = 2.16$, $p = 0.06$, $n_1 = 14$, $n_2 = 36$). Consequently, these

[6] Data for 1999 only because northbound migration velocity was different between the two years (1998 and 1999). $F = 3.25$, $p = 0.005$*, $n_1 = 10$, $n_2 = 35$).

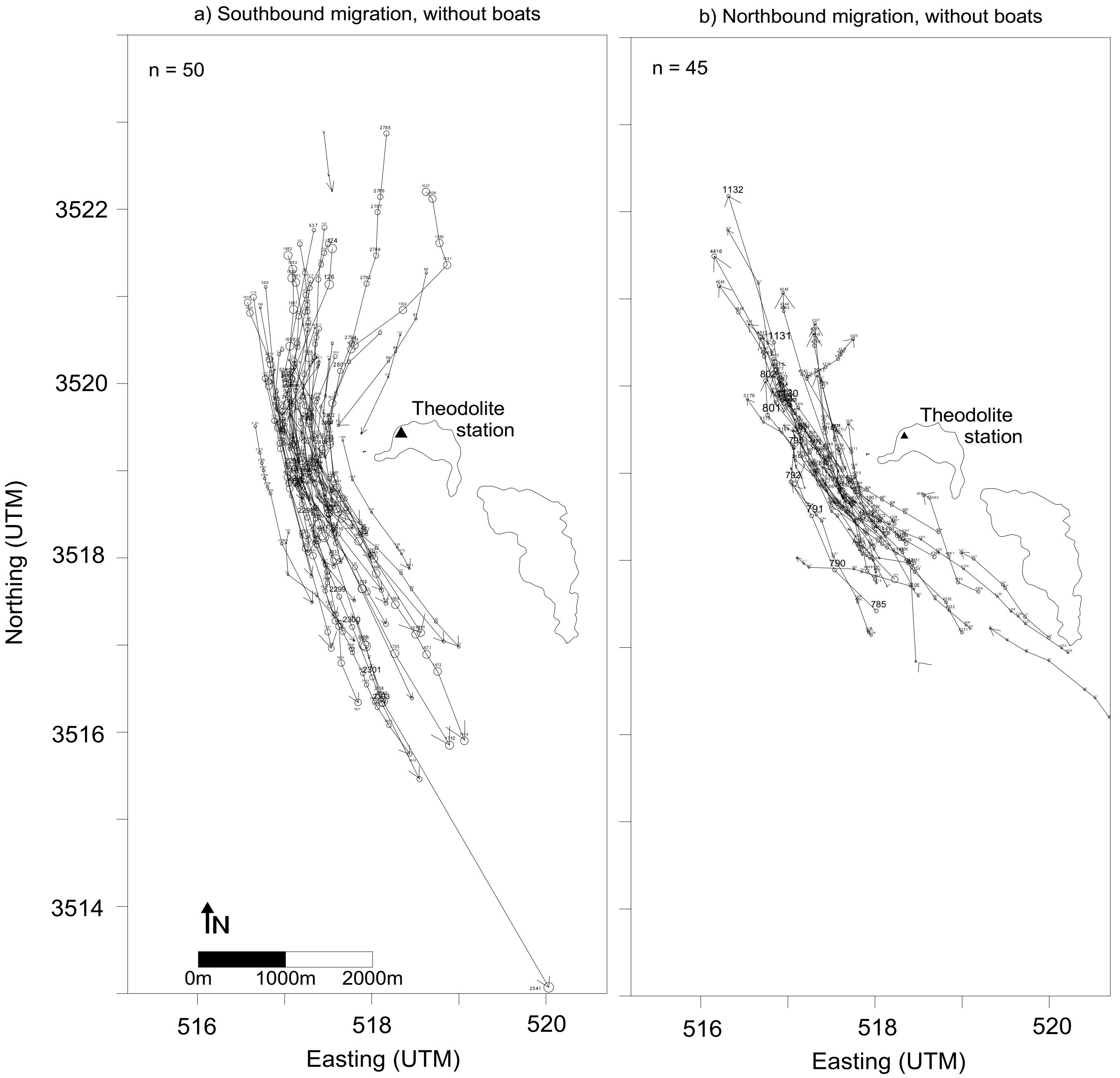

Fig. 3. Tracks of gray whale groups during the southbound and northbound migrations near the Todos Santos Islands from January-March 1998 and 1999. a) and b) without whalewatching or other boats (fishing, cruising or drifting).

Table 2

Angular deviation (*s*) of swimming direction without boats (control observations) and with whalewatching boats (ww), compared by the nonparametric test for dispersion of circular data (Batschelet, 1981). *s* = angular deviation; *Z* = normal approximation of Mann-Whitney *U* (Zar, 1999).

	Southbound		Northbound	
	Without boats	With ww boats	Without boats	With ww boats
n	50	11	45	28
s	14°17’	15°07’	21°15’	25°57’
U	328		846	
Z	0.99		2.45	
p	0.16		0.007*	

Table 3

Angular deviation (*s*) of swimming direction without boats (control observations) and with other boats (fishing, cruising or drifting), compared by the nonparametric test for dispersion of circular data (Batschelet, 1981). s = angular deviation; *Z* = normal approximation of Mann-Whitney *U* (Zar, 1999).

	Southbound		Northbound	
	Without boats	With other boats	Without boats	With other boats
n	50	29	45	19
s	14°17’	15°40’	21°15’	26°28’
U	832		571	
Z	1.09		2.11	
p	0.14		0.02*	

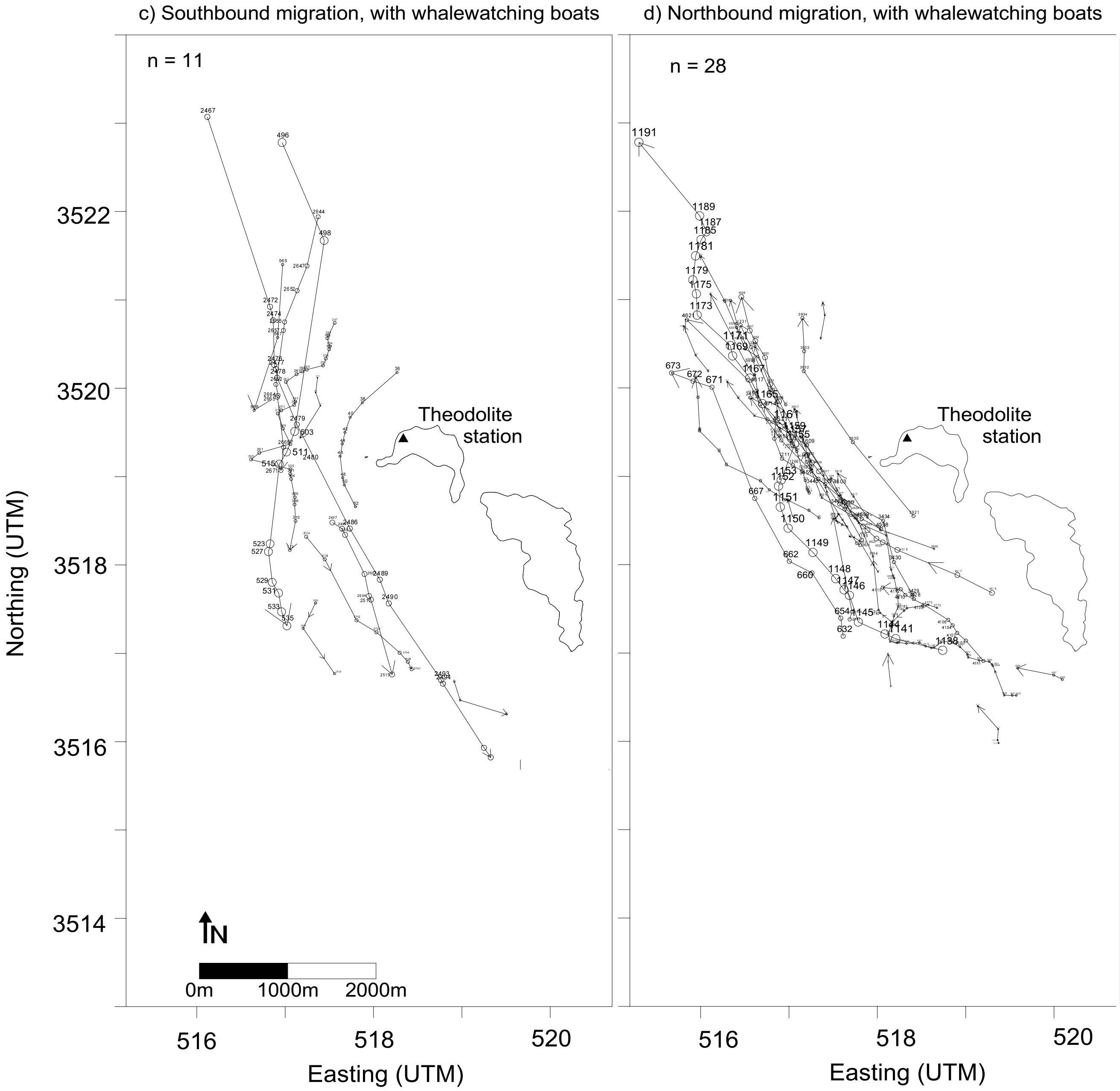

Fig. 3. Tracks of gray whale groups during the southbound and northbound migrations near the Todos Santos Islands from January-March 1998 and 1999. c) and d) with whalewatching boats.

data groups could be pooled for further comparisons. For the northbound migration only data for 1999 were used; the small sample size for 1998 ($n = 3$) prevented further analysis for that year.

Velocity variance showed significant differences between sightings without boats and with whalewatching boats during the southbound ($p < 0.001$) and the northbound migrations ($p = 0.04$, Table 4). Differences were not statistically significant between sightings without boats and with other boats in either of the migrations (Table 5).

Furthermore, significant differences in velocity variance were found during the northbound migration when whalewatching boats approached whales head-on and towards the rear or flanks ($p = 0.015$, Table 6).

DISCUSSION

Migration tracks

At the Todos Santos Islands, although whales were tracked up to 6km from our observation point, the migration corridor seemed to be relatively narrow (2.5km wide, Fig. 3a) when compared with other sites along the USA coast (Reilly *et al.*, 1980; Herzing and Mate, 1984; MBC Applied Environmental Sciences, 1989). However, this should be confirmed by aerial surveys because sightings have been reported offshore in the past (Gilmore, 1955; Leatherwood, 1974). Tracks at this site during the northbound migration are similar in proximity to shore and variable swimming direction compared to other observation points along the migratory route (Malme *et al.*, 1983; Poole, 1984; Green *et al.*, 1995).

Swimming direction

During this investigation, swimming behaviour observed during the northbound migration was more variable than during the southbound migration (Figs 3a and 3b); this was confirmed by the statistically significant difference in angular deviation. Few studies have used theodolite tracking to measure gray whale swimming direction (Malme *et al.*, 1983; 1984; MBC Applied Environmental Sciences, 1989).

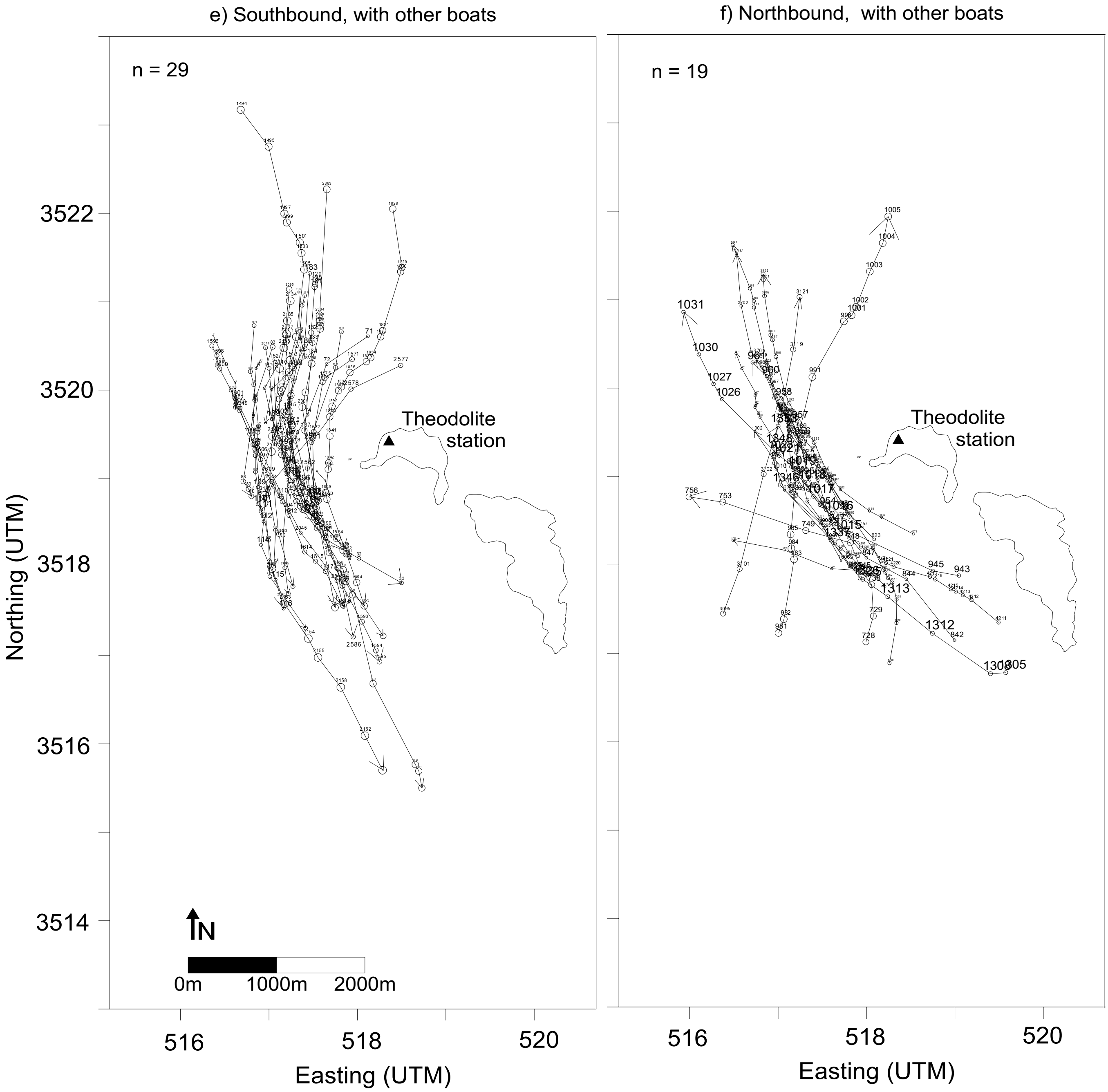

Fig. 3. Tracks of gray whale groups during the southbound and northbound migrations near the Todos Santos Islands from January-March 1998 and 1999. e) and f) with other boats.

Table 4

Variance of swimming velocity without boats and with whalewatching boats, compared by the variance ratio test (Zar, 1999). $\bar{v}$ = mean velocity, s^2_{ln} = natural logarithm of variance.

	Southbound		Northbound (only 1999)	
	Without boats	With ww boats	Without boats	With ww boats
n	50	11	35	25
$\bar{v}$	1.95	2.05	1.39	1.45
s^2_{ln}	0.062	0.430	0.057	0.103
F	6.96		1.87	
p	< 0.001*		0.04*	

Table 5

Variance of swimming velocity without boats and with other boats (fishing, cruising or drifting), compared by the variance ratio test (Zar, 1999). $\bar{v}$ = mean velocity, s^2_{ln} = natural logarithm of variance.

	Southbound		Northbound (only 1999)	
	Without boats	With other boats	Without boats	With other boats
n	50	29	35	9
$\bar{v}$	1.95	1.93	1.39	1.30
s^2_{ln}	0.062	0.054	0.057	0.072
F	1.15		1.26	
p	0.35		0.29	

Table 6

Comparison of swimming direction and velocity variation when whales are approached by whalewatching boats head-on and towards the rear or flanks (only northbound migration). $\bar{\phi}$ = mean angle, s = angular deviation U = test statistic of the nonparametric test for dispersion (Batschelet, 1981). $\bar{v}$ = mean velocity, s^2_{ln} = natural logarithm of variance. F = test statistic of the variance ratio test (Zar, 1999).

Direction			Velocity		
	Head-on	Towards rear or flanks		Head-on	Towards rear or flanks
n	15	13	n	15	13
$\bar{\phi}$	329°34'	323°57'	$\bar{v}$	1.81	1.67
s	28°07'	22°54'	s^2_{ln}	0.305	0.088
U	134		F	3.46	
p	0.05*		p	0.015*	

Only MBC (1989) reported a 'heading standard deviation' for both southbound (27.6°) and northbound migrations (47.4°).

Moreover, the analyses of mean swimming direction did not yield significant differences in the presence and absence of whalewatching and other boats. Even if a whale group changed its swimming direction during a sighting when approached by a whalewatching boat, the average direction would not necessarily be different from the path usually followed. Therefore, the aim was to detect the change in direction during a sighting and the angular deviation (s) was used for this purpose. This variable was significantly different during the northbound migration in the presence of whalewatching and other boats (Tables 2 and 3).

During the southbound migration, swimming direction angular deviation (s) with whalewatching and other boats was not significantly affected (Tables 2 and 3). However, the power of the test could have been compromised because of the small sample size with whalewatching boats ($n = 11$, Table 2; Zar, 1999). Nevertheless, swimming direction did not seem to be disturbed when other boats were in the area, where the sample size was larger during the southbound migration ($n = 29$, Table 3). Therefore, gray whale behaviour seems to be less influenced by boat traffic (whalewatching and other boats) during the southbound than during the northbound migration.

In addition, significant effects were created when whales were approached head-on (Table 6). At Point Sal, California, a vessel that approached the whales head-on caused them to head directly offshore (MBC Applied Environmental Sciences, 1989). At San Ignacio Lagoon, whales exhibited the least amount of disturbance when approached slowly from behind or alongside without abrupt changes in engine speed (Swartz and Jones, 1978).

Although concern has been expressed about reactions of gray whales to boat traffic since the earliest days of whalewatching in San Diego about 40 years ago (Wilke and Fiscus, 1961), few studies have investigated the effects of vessels on gray whale behaviour or demography. Most of the accounts of observed behaviour disturbance along the migratory route have been anecdotal and none has been subject to systematic research. Wyrick (1954) described the changes in direction of southbound migrating gray whales followed on a research vessel close to Point Loma, California. Sumich (1983) eliminated from his study on gray whale energy consumption those sightings where boats were at distances less than 100m from the whale group, where he assumed that swimming behaviour was modified. Malme *et al.* (1983; 1984) found that whales would change their course (measured by theodolite) at less than 200m from a sound source. MBC (1989) reported two instances where whales appeared to change direction in the proximity of boats. Moore and Clarke (In Press) reported that 'gray whales sometimes change course and alter their swimming speed and respiratory patterns when followed by whalewatching boats'. Only recently has theodolite tracking been employed to evaluate gray whale behaviour when approached by whalewatching boats on the migratory route (Schwarz, pers. comm. in San Diego; this study) and at Bahía Magdalena, Mexico, a breeding lagoon (Ollervides *et al.*, 2000).

Swimming velocity

The mean swimming velocities estimated at the Todos Santos Islands for the southbound (1.95m/s) and northbound (1.44m/s) migrations are comparable to the measurements achieved by theodolite tracking at other sites along the California coast (Malme *et al.*, 1983; 1984; Sumich, 1983; MBC Applied Environmental Sciences, 1989). For many years, southbound gray whales have been reported to travel faster than northbound whales (Gilmore, 1960; Pike, 1962), and this difference was statistically significant in this investigation.

The estimated mean swimming velocity in this study did not increase significantly in the presence of whalewatching boats. Velocity variance, however, was significantly different in the presence of whalewatching boats compared to without boats, both during southbound and northbound migrations (Table 4). While navigating on a research vessel behind gray whales at Point Loma, Wyrick (1954) noticed an increase in swimming velocity. Kenyon (1973, in Bird, 1983) observed that small boats approaching gray whales to less than 20m would incite the whales to move away rapidly. By contrast, gray whales observed in this study in the presence of fishing, cruising or drifting boats seemed to reduce their mean velocity (Table 5), although this was not significantly different from their 'natural' behaviour without boats. In addition, comparison of velocity variance without and with other boats did not yield significant differences (Table 5). Gray whales exposed to oil exploration sound sources reduced their swimming speed and this was interpreted as 'a cautious pattern of movement' (Malme *et al.*, 1983). A similar behaviour was observed at Point Sal, California, when gray whales were inadvertently approached by fishing vessels (MBC Applied Environmental Sciences, 1989).

The intentional approach of vessels might elicit an escape reaction in whales, and the vessels' speed, direction, distance and sound seem to be important factors (Bird, 1983). In this study, whale velocity variance was significantly higher when whalewatching vessels approached the whales head-on (this occurred in 54% of the analysed sightings during the northbound migration), instead of approaches towards the rear or flanks (Table 6). A change in velocity was also observed during the head-on approach of a fishing vessel at Point Sal (MBC Applied Environmental Sciences, 1989). The vessels' proximity and speed probably resembles a chase as experienced by gray whales when pursued by killer whales (Goley and Straley, 1994) or by aboriginal subsistence hunters off Chukotka (IWC, 1993).

Gray whales exhibit quite different behaviour during the southbound and northbound migrations. It could be hypothesised that the straight paths, higher velocity and greater distance from shore when heading southwards would seem to be related to a certain drive to arrive at the breeding sites. This might be related to high hormonal levels; however, this would have to be confirmed by a physiological study. As to the northbound migration (Phase A), the slower swimming pace could be related to energetic expenditure. Whales have fasted for several months and may have less energy to travel at the same speed as during the southbound migration. The more variable swimming path and closer distance to shore during the northbound migration may also be related to the whales' search for food sources along the coast.

An alternative or complementary hypothesis to explain the differences in swimming speed between southbound and northbound migrations would be related to the California Current (CC). This is the eastern limb of the large-scale, anticyclonic North Pacific gyre. Except near the coast, the CC is a surface (0-300m deep) current which carries water towards the equator throughout the year along the west coast of North America to the North Equatorial Current (Lynn and Simpson, 1987). In January (during the gray whale's southbound migration), the flow off Ensenada has a magnitude of 1-4cm/s that becomes stronger in February, reaching its peak speed (8cm/s) in March (Lynn and Simpson, 1987), during the gray whale's northbound migration. Therefore, it would seem plausible that whales swim slower during the northbound migration because they are swimming 'against the current'.

The CC, however, is a complex current system with a seasonal variability (Lynn and Simpson, 1987). Although the flow towards the equator is dominant throughout the year at all latitudes, a surface countercurrent develops seasonally along the California and northern Baja California coasts (south to Ensenada). This Inshore Countercurrent (IC) develops near the coast (within 150km) and is strongest from October-December (Lynn and Simpson, 1987), when whales are travelling south. However, when gray whales migrate northwards, the equatorward flow of the CC is strongest (20cm/s) at Ensenada's latitude from February-April (Lynn and Simpson, 1987). This could mean that gray whales swim against the current during most of their migration (both south and north). Given this, it seems probable that the timing of the gray whale migration is more related to food availability and reproductive drive than to ocean circulation.

Potential long-term effects of whalewatching on gray whales

Short-term effects of whalewatching mainly refer to behavioural, physiological or acoustic reactions of the animals to interactions with boats or swimmers. Assessments of long-term impacts are aimed at measuring changes in population parameters (distribution, abundance, mortality), physical condition of individuals and habituation or tolerance (IFAW, 1995). The IWC Scientific Committee has agreed that in instances where annual reproduction occurs in a specific location (as in gray whales), any detrimental effects from exposure to whalewatching in those areas could affect an entire year's production and ultimately the status of the stock (IWC, 2000).

During the 1970s, after a five-year study at San Ignacio Lagoon, no changes in distribution had been detected and relative abundance had increased (Jones and Swartz, 1984). Urbán *et al.* (1997) detected a decrease in whale density in the lagoon compared to earlier studies by Jones and Swartz (1984). This variation was perhaps due to natural modification in timing and movements of the whales in response to changes in environmental factors or human activities such as whalewatching (Urbán *et al.*, 1997). More recent surveys indicated that abundance was increasing and the distribution of whales in the lagoon followed the same pattern as in earlier years (Urbán *et al.*, 1998).

With respect to the gray whale's migratory route, during the 1960s increasing boat traffic in San Diego, USA, appeared to be causing an increasing proportion of gray whales to migrate far offshore (Rice, 1965; Gilmore, 1978; Reilly *et al.*, 1980). Whalewatching by recreational and commercial craft may negatively impact migrating gray whales by interrupting swimming patterns and thereby increasing energy consumption (IWC, 1993). In view of the complexity in assessing long-term effects of whalewatching on cetaceans, the IWC Scientific Committee agreed that research should focus on biologically significant effects (acoustic exposures, disease and energetic considerations) (IWC, 2001). Energetic expenditure, measured by swimming speed and respiratory rates (Sumich, 1983) may be used in appropriate models to develop 'critical response thresholds'. Speed and respiratory rates were recorded during this study, so these data could be analysed in the future to evaluate potential impacts of biological significance for gray whales at the Todos Santos Islands during 1998 and 1999.

Implications for regulation of whalewatching in Ensenada, Baja California, Mexico

The Mexican Official Law NOM-131-ECOL-1998 is explicit about approach manoeuvres permitted for whales and other rules. The different characteristics of gray whale behaviour and whalewatching activities in each whalewatching area have motivated new studies to adapt the regulations to each lagoon and to Todos Santos Bay (Ollervides and Pérez-Cortés, 2000; Ollervides *et al.*, 2000).

Even though head-on approaches are prohibited by law, they occurred often (54% of sightings during the northbound migration) in this study in the Todos Santos Bay whalewatching area because tour operators depart the bay north and south of the islands randomly, without considering the migration phase (northbound or southbound). Once whalewatching boats arrive at the Todos Santos Islands, they circle around the islands and then return to Ensenada (Fig. 2). Following the results of this investigation (significant changes in whale swimming speed variance and direction angular deviation) an addition is proposed to the Mexican whalewatching law with respect to Todos Santos Bay. In order to prevent unintentional head-on approaches by whalewatching vessels, these should depart Todos Santos Bay north of the Todos Santos Islands during the southbound migration (until mid-February). Conversely, vessels should exit the bay south of the islands during the northbound migration (after mid-February, see Fig. 2).

Regulation of whalewatching has been questioned by some tour operators because long-term effects of whalewatching have been determined only at one site (Wilson, 1994). The precautionary principle, adopted by the United Nations Conference on Environment and Development (UNCED) urges caution when making decisions about systems that are not fully understood (Meffe and Carroll, 1997). In the case of Todos Santos Bay, such a principle suggests that it would be unwise to wait until it can be shown that the gray whale's migratory corridor has been displaced (as in San Diego) to put regulation into action, because this long-term effect may be irreversible. Management has to be based on the best available knowledge (such as the short-term effects identified in the present investigation) and the precautionary principle. As more research and experience is accumulated, regulation and management should be adapted collectively (with stakeholders' participation, including tour operators) by loosening or tightening the limits established on the tourist activity. Self-regulation on a voluntary basis, coupled with education of operators and the public, is regarded by many as being the most effective means of ensuring compliance with all regulations in the long term (IFAW, 1999).

During growth and development of human settlements, careful comprehensive planning is necessary to accommodate the needs of developers and wildlife (Compeàn *et al.*, 1995). This seems to be currently underway in Ensenada with respect to whalewatching, since permit issue for commercial whalewatching is controlled by the Mexican government (SEMARNAP, 2000). However, there may still be a need for further regulatory and management actions to reduce potential short- and long-term effects on migrating gray whales passing Todos Santos Bay.

ACKNOWLEDGEMENTS

Data collection in the field was supported by Y. Schramm, E. Morteo, J. Hernández, O. Guzón, S. Mejía, E. Kim and P. Batta of Investigación y Conservación de Mamíferos Marinos de Ensenada, A.C. A. Chee Barragán, Universidad Autónoma de Baja California (UABC), measured the height of the lighthouse tower. Lorenzo Rojas (Instituto Nacional de la Pesca), J. de la Rosa, K. Murphy, R. Enríquez, R. Durazo and Y. Schramm (UABC), reviewed earlier drafts of this paper. Special thanks to Horacio de la Cueva, Centro de Investigación Científica y Educación Superior de Ensenada (CICESE) for statistical advice. Field work and equipment were financed by Fondo Mexicano para la Conservación de la Naturaleza and PADI Foundation. Abulones Cultivados, S. de R.L. gave free boat transport to the island. G. Heckel received grants from Consejo Nacional de Ciencia y Tecnología, CICESE and Misener Constru-Marina. This research was conducted under permits DGG/SP/553/97, DGG/SP/1388/98 (Secretaría de Gobernación), DOO 750/1063/98 and DOO 750.-13320/98 (Secretaría de Medio Ambiente, Recursos Naturales y Pesca).

REFERENCES

Batschelet, E. 1981. *Circular statistics in biology*. Academic Press, London. 371pp.

Bird, J.E. 1983. The California gray whale (*Eschrichtius robustus*): A review of the literature on migratory and behavioral characteristics. *In:* C.I. Malme, P.R. Miles, C.W. Clark, P. Tyack and J.E. Bird (eds.) *Investigation of the Potential Effects of Underwater Noise from Petroleum Industry Activities on Migrating Gray Whale Behaviour. Phase 1, January 1983 Migration*. Report no. MMS/AK/ESU-83-020 presented to the US Minerals Management Service, Anchorage, Alaska. 250pp. [Available from *http://www.mms.gov*].

Cipriano, R. 1990. *User's Manual T-TRAK Version 1.0. Theodolite-Tracking Data Analysis (for IBM-compatible Computers)*. University of Arizona, Arizona, USA. 38pp.

Compeán J, G., Mate, B., Pérez-Cortés M, H., Swartz, S. and Ulloa R, P. 1995. Report of the Scientific Committee. Annex F. Report of the Sub-Committee on Aboriginal Subsistence Whaling. Appendix 10. Further thoughts on tourism and other developments in gray whale critical habitats. *Rep. int. Whal. Commn* 45:160-1.

Gilmore, R.M. 1955. The return of the gray whale. *Sci. Am.* 192(1):62-7.

Gilmore, R.M. 1960. Census and migration of the California gray whale. *Norsk Hvalfangsttid.* 49(9):409-31.

Gilmore, R.M. 1978. Some news and views of the gray whale, 1977 - Migration south and north along and between the islands of southern California. *Whalewatcher* 12(2):9-13.

Goley, P.D. and Straley, J.M. 1994. Attack on gray whales (*Eschrichtius robustus*) in Monterey Bay, California, by killer whales (*Orcinus orca*) previously identified in Glacier Bay, Alaska. *Can. J. Zool.* 72(8):1528-30.

Green, G.A., Brueggeman, J.J., Grotefendt, R.A. and Bowlby, C.E. 1995. Offshore distances of gray whales migrating along the Oregon and Washington coasts, 1990. *Northwest Sci.* 69(3):223-7.

Greenhood, D. 1964. *Mapping*. University of Chicago Press, Chicago, Illinois, USA. 289pp.

Herzing, D.L. and Mate, B.R. 1984. Gray whale migrations along the Oregon coast, 1978-1981. pp. 289-307. *In:* M.L. Jones, S.L. Swartz and S. Leatherwood (eds.) *The Gray Whale, Eschrichtius robustus*. Academic Press Inc., Orlando Florida. xxiv+600pp.

Instituto Nacional de Estadistica, Geografía e Informática, 1982. Carta H11-2, Ensenada, Baja California. INEGI, México, D.F. México. [In Spanish. Available from: *http://www.inegi.gob.mx*].

International Fund for Animal Welfare. 1995. Report of the Workshop on the Scientific Aspects of Managing Whalewatching, Montecastello di Vibio, Italy, 30 March - 4 April 1995. Paper SC/47/O18 presented to the IWC Scientific Committee, May 1995 (unpublished). 45pp. [Paper available from the Office of this Journal].

International Fund for Animal Welfare. 1999. Report of the Workshop on the Legal Aspects of Whale Watching, Punta Arenas, Chile, 17-20 November 1997. Paper IWC/51/WW1 presented to the IWC, Grenada, WI, May 1999 (unpublished). 38pp. [Paper available from the Office of this Journal].

International Whaling Commission. 1993. Report of the Special Meeting of the Scientific Committee on the Assessment of Gray Whales, Seattle, 23-27 April 1990. *Rep. int. Whal. Commn* 43:241-59.

International Whaling Commission. 1995. Chairman's Report of the Forty-Sixth Annual Meeting. *Rep. int. Whal. Commn* 45:15-52.

International Whaling Commission. 2000. Chairman's Report of the Fifty-First Annual Meeting. *Ann. Rep. Int. Whaling Comm.* 1999:7-50.

International Whaling Commission. 2001. Report of the Scientific Committee. *J. Cetacean Res. Manage. (Suppl.)* 3:1-76.

Jones, M.L. and Swartz, S.L. 1984. Demography and phenology of gray whales and evaluation of whale-watching activities in Laguna San Ignacio, Baja California Sur, Mexico. pp. 309-74. *In:* M.L. Jones, S.L. Swartz and S. Leatherwood (eds.) *The Gray Whale, Eschrichtius robustus*. Academic Press, Inc., Orlando, Florida. xxiv+600pp.

Leatherwood, J.S. 1974. Aerial observations of migrating gray whales, *Eschrichtius robustus*, off southern California, 1969-72. *Mar. Fish. Rev.* 36(4):45-9.

Lynn, R.J. and Simpson, J.J. 1987. The California current system: the seasonal variability of its physical characteristics. *J. Geophys. Res.* 92(C12):12,947-66.

Malme, C.I., Miles, P.I., Clark, C.W., Tyack, P. and Bird, J.E. 1983. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behaviour. Report No. 5366, report prepared by Bolt, Beranek and Newman Inc., Cambridge, MA, for the Minerals Management Service, Anchorage, AK. 325pp. [Available from: *http://www.mms.gov*].

Malme, C.I., Miles, P.I., Clark, C.W., Tyack, P. and Bird, J.E. 1984. Investigations of the potential effects of underwater noise from petroleum industry activities on migrating gray whale behavior - Phase 2: January 1984 migration. Final Report No. 5586 report prepared by Bolt, Beranek and Newman Inc., Cambridge, MA for the US Minerals Management Service, Anchorage, AK. BBN, Inc. NTIS PB86-218377. 297pp. [Available from *http://www.mms.gov*].

Manfredo, M.J., Lee, M. and Ford, K. 1988. Alternative markets for charterboat operators affected by declining salmon allocations in Oregon. *Coastal Manage.* 16(3):215-27.

MBC Applied Environmental Sciences. 1989. Gray whale monitoring study. Final report to US Department of the Interior, Minerals Management Service, Costa Mesa, CA. (unpublished). 99pp. [Available from *http://www.mms.gov*].

Meffe, G.K. and Carroll, C.R. 1997. *Principles of Conservation Biology. 2nd Edition*. Sinauer Associates, Inc, Sunderland, MA, USA. 729pp.

Moore, S.E. and Clarke, J.T. In press. Potential impact of offshore human activities on gray whales. *J. Cetacean Res. Manage.* 4(1).

Neave, H.R. and Worthingon, P.L.B. 1988. *Distribution-free Tests*. Unwin Hyman Ltd, London, UK. 430pp.

NOAA (US National Oceanic and Atmospheric Administration). 1999. Observed and verified water levels at San Diego CA station. US National Ocean Service - Center for Operational Oceanographic Products and Services. [Available from: *http://www.opsd.nos.noaa.gov/datares.htm*].

Ollervides, F. and Pérez-Cortés, H. 2000. A summary of investigations of whalewatching impacts on the gray whale (*Eschrichtius robustus*) at Bahía Magdalena, Mexico. Paper SC/52/WW10 presented to IWC Scientific Committee, June 2000, in Adelaide, Australia. [Available from the Office of this Journal].

Ollervides, F., Pettis, J. and Richlen, M. 2000. Effects of boat traffic on gray whales (*Eschrictius robustus*) off San Carlos, Baja California Sur, Mexico: a preliminary report. Paper presented to the XXV Reunión Internacional para el Estudio de los Mamiferos Marinos, La Paz, Mexico, May 2000 (unpublished). 1p. [Available from *http://somemma.ens.uabc.mx*].

Pike, G.C. 1962. Migration and feeding of the gray whale (*Eschrichtius gibbosus*). *J. Fish. Res. Bd Can.* 19(5):815-38.

Poole, M.M. 1984. Migration corridors of gray whales along the central California coast, 1980-1982. pp. 389-407. *In:* M.L. Jones, S.L. Swartz and S. Leatherwood (eds.) *The Gray Whale, Eschrichtius robustus*. Academic Press, Inc., Orlando, Florida. xxiv+600pp.

Reilly, S.B., Rice, D.W. and Wolman, A.A. 1980. Preliminary population estimate for the California gray whale based upon Monterey shore censuses, 1967-68 to 1978/79. *Rep. int. Whal. Commn* 30:359-68.

Reilly, S.B., Rice, D.W. and Wolman, A.A. 1983. Population assessment of the gray whale, *Eschrichtius robustus*, from California shore censuses, 1967-80. *Fish. Bull.* 81(2):267-81.

Reyna M, M.I. and Alcántara O, S. 2000. A global perspective of whalewatching activities in Mexico, 1999. Paper presented at the XXV Reunión Internacional para el Estudio de los Mamíferos Marinos, May 2000 (unpublished). [Available from *http://somemma.ens.uabc.mx*].

Rice, D.W. 1965. Offshore southward migration of gray whales off Southern California. *J. Mammal.* 46(3):504-5.

SEMARNAP, Secretaria de Medio Ambiente, Recursos Naturales y Pesca. 2000. Norma Oficial Mexicana NOM-131-ECOL-1998, que establece lineamientos y especificaciones para el desarrollo de actividades de observación de ballenas, relativas a su protección y la conservación de su hábitat. Diario Oficial de la Federación, 10 de enero de 2000. pp.11-17. [In Spanish]. [Available from *http://www.ine.gob.mx/dgra/normas/rec_nat/no_131.htm*].

Sumich, J.L. 1983. Swimming velocities, breathing patterns, and estimated costs of locomotion in migrating gray whales, *Eschrichtius robustus*. *Can. J. Zool.* 61(3):647-52.

Swartz, S.L. and Jones, M.L. 1978. The evaluation of human activities on gray whales, *Eschrictius robustus*, in Laguna San Ignacio, Baja California Sur, Mexico. Report no. NTIS PB82-123373 presented to the US Marine Mammal Commission, Washington, DC, USA (unpublished). 34pp. [Available from *http://www.ntis.gov*].

Urbán-R, J., Gómez-Gallardo U, A., Flores de Sahagún, V., Cifuentes L, J., Ludwig, S. and Palmeros R, M. 1997. Gray whale studies at Laguna San Ignacio, B.C.S., Mexico, winter 1996. *Rep. int. Whal. Commn* 47:625-33.

Urbán-R, J., Gómez-Gallardo U, A. and Palmeros-R, M. 1998. A note on the 1997 gray whale studies at Laguna San Ignacio, B.C.S., Mexico. *Rep. int. Whal. Commn* 48:513-6.

Wilke, F. and Fiscus, C.H. 1961. Gray whale observation. *J. Mammal.* 42(1):108-9.

Wilson, B. 1994. Review of the Dolphin Management at Monkey Mia. Report to the Executive Director, Department of Conservation and Land Management, Western Australia. 37pp.

Würsig, B., Cipriano, F. and Würsig, M. 1991. Dolphin movement patterns: information from radio and theodolite tracking studies. pp. 79-111. *In:* K. Pryor and K.S. Norris (eds.) *Dolphin Societies, Discoveries and Puzzles*. University of California Press, Berkeley, California, USA. 397pp.

Wyrick, R.F. 1954. Observations on the movements of the Pacific gray whale *Eschrichtius glaucus* (Cope). *J. Mammal.* 35:593-8.

Zar, J.H. 1999. *Biostatistical Analysis*. 4th Edn. Prentice Hall, New Jersey, USA. 663pp.