

Use of an electronic theodolite in the study of movements of the bottlenose dolphin (*Tursiops truncatus*) in the Sado Estuary, Portugal

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Abstract

An electronic theodolite was used to track the movement patterns of bottlenose dolphins (*Tursiops truncatus*) inhabiting the Sado Estuary, Portugal, during several periods between June 1986 and December 1993. Recordings were obtained from a shore vantage point, 56–59 m above sea level, which allowed the computation of the surface positions and speed of one, or several dolphins within the study area at a time.

In 14 of the 35 observations, dolphins were observed as a single, tight group transiting through the study area. In the remaining 21 incidents, the animals were observed moving, directionally or erratically, engaging in different behaviours and spreading over an area of 660 to 480 000 m². The average size of these areas was 34 000 m² for groups comprising 6–10 animals, and 64 000 m² for groups of 16–20 animals. The area covered, and the speed of these groups, varied significantly with water depth. Overall, the dolphins traveled at speeds of up to 3.2 ms⁻¹.

The dolphins appeared to come into the Sado Estuary most often during the morning hours and with flood tide. In the early afternoon, the animals were frequently engaged in foraging, non-directional movement and travel. At the beginning of ebb tide, and throughout the afternoon hours, the dolphins gradually moved downstream, eventually leaving the study area.

Key words: movements, spatial pattern, swim speed, theodolite tracking, Sado estuary, bottlenose dolphin, *Tursiops truncatus*.

Introduction

Theodolites have been successfully used since the 1970s to study a variety of cetacean species in various locations around the world (Würsig & Würsig, 1979; Harzen, 1989; Acevedo, 1991; Kruse, 1991; Goodson & Mayo, 1995). In all instances, the advantage of employing theodolite technology has

been the ability to observe the animals, undisturbed and from a distance, while at the same time obtain relatively precise data on their surfacing positions, movement patterns, and travel speed, usually ignoring the effects of water currents.

Acevedo (1991) studied interactions between boats and bottlenose dolphins as part of a larger project looking at behaviour and movement patterns in the entrance to Ensenada de La Paz, Mexico and used a surveyor's theodolite to record the nearest position of a boat and the center of the dolphin group. Acevedo was able to distinguish four types of boat approaches, including boats cruising more than 25 m away from the animals, in a range of 5–25 m and 5 m of the dolphins, and boats following the animals at distances ranging from 2–10 m. Acevedo (1991) concluded that vessels driving through the area did not significantly modify the movement patterns or behaviour of the dolphins in the study area.

Goodson & Mayo (1995) employed electronic theodolites to study interactions between free-ranging bottlenose dolphins and passive acoustic gill-net deterrent devices in Moray Firth, Scotland. They concluded that theodolite tracking data (i.e., plotting the course of the animals) did greatly facilitated the analysis and interpretation of the animal's sonar signals, and also allowed the easy extraction of breathing rates and swimming speeds from the tracking data. The maximum speed recorded for bottlenose dolphins in Moray Firth was 8 m/s. The average speed varied between 0.8 m/s and 2 m/s.

Kruse (1991) tracked killer whales (*Orcinus orca*) and boats with a Nikon (NT2A) theodolite from a land-based position, 58.8 m above mean low tide, overlooking Johnstone Strait, British Columbia. Three-quarters of her theodolite readings were within 3 km of the observation point. The swimming speed of the animals increased as more boats approached. In fact, killer whales with boats swam on average 1.4 times faster than when undisturbed, travelling at an average speed of 1.4 m/s. Kruse also found that the approach of boats clearly affected



Figure 1. The study area.

the movement patterns of killer whales, which typically responded by increasing their swimming speed, and tended to swim toward open waters.

Movement patterns of coastal bottlenose dolphins have been studied in many places, including the Californian coast, Ecuador, Argentina, the Gulf of Mexico, the east and west coast of Florida, South Africa, Portugal and Scotland (Hanson, 1990; Felix, 1994; Acevedo & Würsig, 1991; Würsig & Würsig, 1979; Shane, 1987; Henningsen, 1991; Irvine *et al.*, 1981; Saayman *et al.*, 1973; Cockcroft *et al.*, 1990; 1992; d.Santos & Lacerda, 1987; Harzen, 1995; Wilson *et al.*, 1994). Many studies revealed short-term movements of bottlenose dolphins, associated to a variety of factors, including tidal and diurnal cycles of their prey. Saayman *et al.* (1973) found that bottlenose dolphins entered Plettenberg Bay, South Africa, in the morning and afternoon primarily to feed. It was not discussed whether the animals might have been following the diurnal cycles of their prey. Würsig & Würsig (1979) reported that bottlenose dolphins in Golfo San Jose, Argentina, moved into deeper water dur-

ing mid-day hours, where they engaged in feeding and other behaviours at different depths.

Tidal currents often affect short-term movements of bottlenose dolphins. Near Sarasota, Florida, dolphins moved onto shallow sea grass flats with the incoming tide and engaged in feeding (probably on mullet) in small groups (Wells *et al.*, 1980; Irvine *et al.*, 1981). In Aransas Pass, Texas, dolphins were observed stationing themselves against the tide, a behaviour that was first related to 'resting' (Shane *et al.*, 1986), and later re-interpreted as a feeding strategy (Shane, 1990). Such movement against the tides was also reported by Gruber (1981). In contrast, Irvine & Wells (1972) and Würsig & Würsig (1979) reported on a movement with the tides; however, Felix (1994) found no significant correlation between the movement of bottlenose dolphins and tidal current in the Gulf of Guayaquil, Ecuador.

In summary, coastal bottlenose dolphins can move with or against the tide (and concentrations of food), or can exhibit regular diurnal movement patterns. The evidence also shows that bottlenose

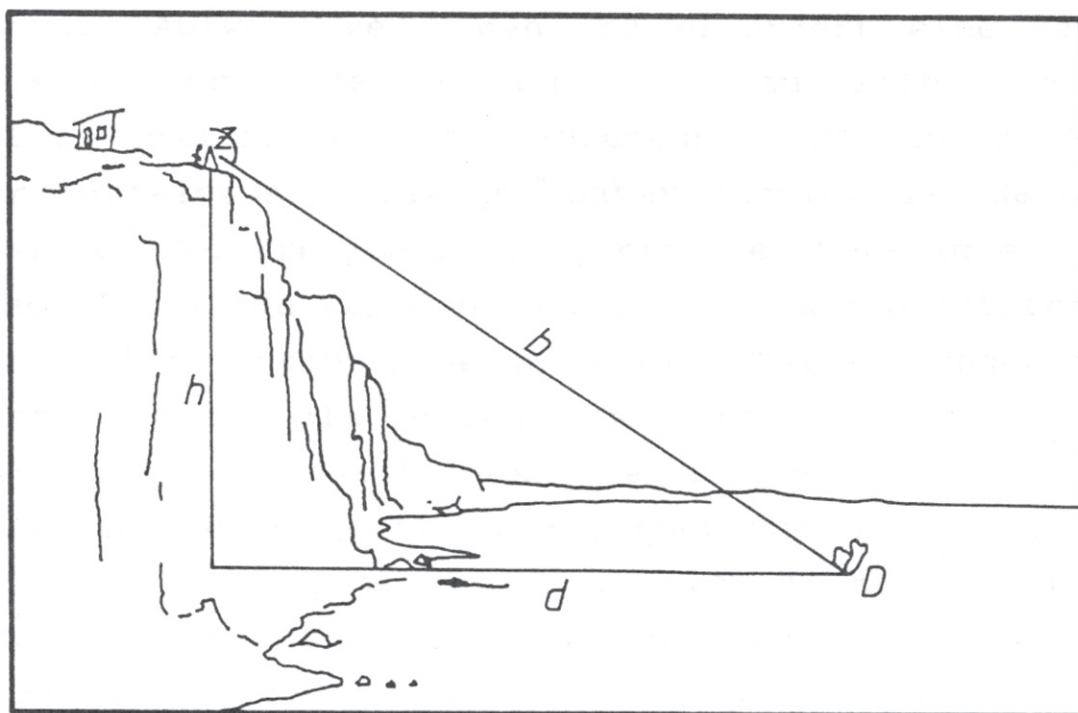


Figure 2. Trigonometry of theodolite tracking.

dolphins generally exhibit preferences for certain locations or areas within their habitat, indicating that they remember, or have learned, when and where food resources can be exploited most efficiently.

Materials and Methods

Study area

The study area, comprising about 150 km², is centred on the estuary of the River Sado, which meets the Atlantic Ocean on the western coast of Portugal, near the city of Setúbal. The river mouth is narrow with a 2 km span located at approximately 38°29'N, 08°55'W. The long, sandy and narrow peninsula of Troia, fed by the south-north littoral drift, is situated in front of the Bay of Setúbal (Fig. 1). The study area also includes the western adjacent rocky shoreline of Arrábida and furthers south the open sandy beaches of the Troia Peninsula.

Research effort

Observations were carried-out during June through August in 1986 and 1987, and from May through October in 1992 and May through December 1993. Out of 1507 h in the field, 431.5 h were spent in

direct dolphin observation. Dolphins were tracked with the theodolite for 75 h.

The shore vantage point atop a 55 m tall building, situated on the tip of the peninsula, provided an almost complete view of the study area (see Fig. 1). To detect the animals from shore, we used binoculars along with the monocular of the theodolite, which was also used to record the position of the animals within the study area.

Theodolite tracking technique

Roger Payne and his associates originally developed the technique of tracking dolphins by theodolite in the 1970s. Theodolites are surveying instruments capable of measuring angles with great accuracy, typically 10 or 20 s of arc. If the height above sea level is known, simple trigonometrical equations allow calculation of the surfacing position of the dolphin in the water (see Fig. 2).

In principle, the measurement of a depression angle and an angle in the azimuth plane from the cliff top will give the surface position of the target, as long as a continuous compensation for tidal height change is provided (for more details, see Würsig *et al.*, 1991; Mayo & Goodson, 1993). The accuracy of the measurements can be greatly improved if two theodolites are employed, separated

Table 1. Distance error for minimum and maximum altitude above sea level.

Distance [in meters]	Distance Error (m _e) [in meters]	
	h ⁰ =55.9	h ¹ =58.9
100	0.2	0.2
500	1.3	1.2
1000	2.8	2.7
2000	6.7	6.4
3000	11.8	11.2
4000	18.0	17.1
5000	25.3	24.0

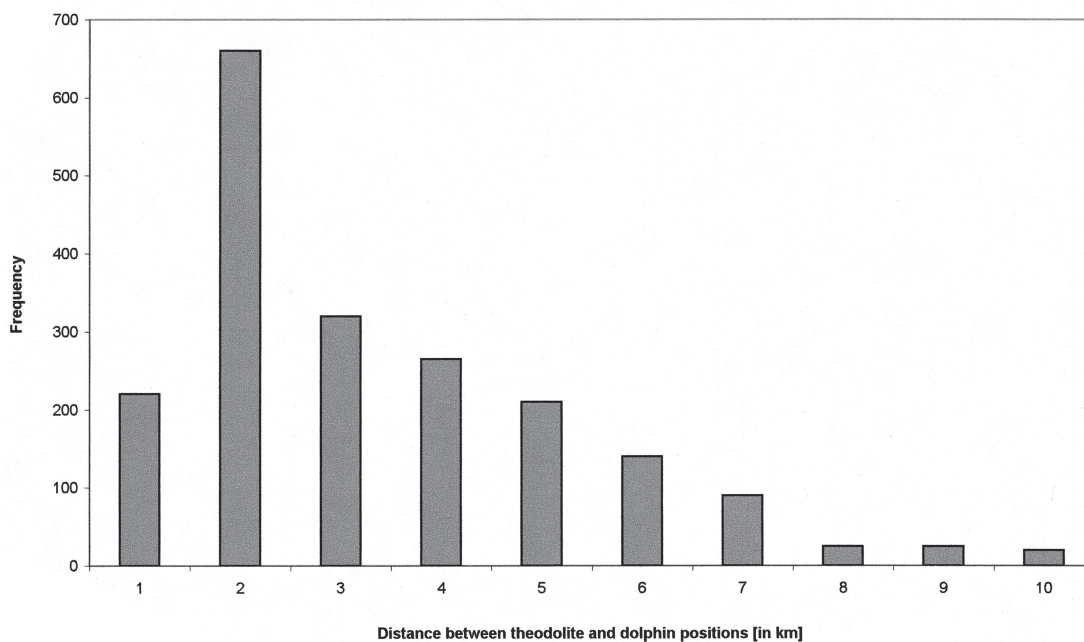
by a known distance and with bearings taken simultaneously (i.e., cross bearings). However, this requires twice as much effort and demands a degree of coordination of both observers difficult to achieve.

Theodolite tracking data collection

The theodolite was set up over a fixed point atop the building used for observations (see Fig. 1). The height of the theodolite position above sea level varied between 55.9 and 58.9 m, with the adjustments for tidal changes made in 0.25 m increments

that were read off a scale mounted on a concrete block situated directly in front of the theodolite position. The vertical and horizontal angles were zeroed from the horizontal plane through the instrument and using a distant fixed point, respectively. The electronic theodolite (Zeiss Eth4) was connected to a Husky field computer, run with a software package developed for this study. This setup allowed us to record the position of the dolphins in degrees or as x and y coordinates, and other observational and environmental data within the study area, with the push of a single button.

As long as the animals swam in a tight group, each theodolite reading focused on the front animal(s) as a representation of the entire group. A group was defined as any number of dolphins observed in apparent association, moving in the same direction and often, but not always, engaged in the same activity (Shane, 1990). With each reading plotted as a single point (or dot), the course of the animals through the observation area could be illustrated by merely connecting the dots. Whenever the group split into subgroups, whose members moved into the same general direction but could be monitored individually, the readings resulted in several, parallel, divergent or convergent lines. When the group split into widely dispersed subgroups, moving erratically, but still individually recognizable, theodolite readings for all visible

**Figure 3.** Frequency distribution of theodolite readings for dolphin groups within 1 km distance intervals relative to the theodolite position.

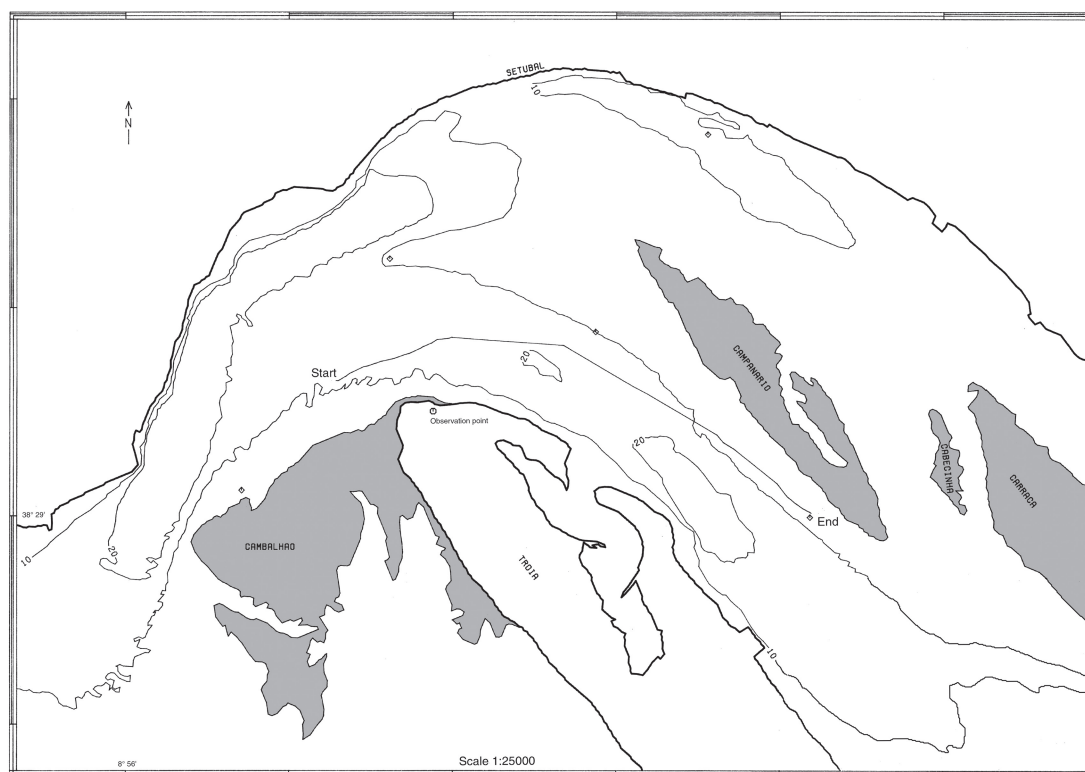


Figure 4. Sample theodolite track of a group of dolphins exhibiting directional movement, tracked from 9.03 a.m. (start) to 10.20 a.m. (end). Total distance traveled was 4825 m.

subgroups were obtained almost simultaneously (≤ 10 – 20 s, or less). The resulting three or more points, each representing one subgroup, were used to calculate the area covered by the subgroups. Speed was calculated by determining the time between two successive readings, and only for identifiable groups transiting through the area. Time intervals ranged from 30 s to 3 min.

Theodolite tracking—data analysis

Taking into consideration the accuracy of the instrument (0.002 gon) and the altitude error (0.125 m), the possible distance error (m_e) is a measure of the position accuracy of the tracked animals in space. With tidal currents resulting in sea level changes of up to 3 m, the distance error was calculated for both minimum and maximum altitudes of 55.9 (h^0) and 58.9 m (h^1), respectively (see Table 1).

In 85% of all cases, the animals were tracked within 5 km, and in more than 50% of cases the dolphins were within a range of 3 km (see Fig. 3). After the map of the study area (1:25 000) was digitized, the theodolite recordings (x and y values)

were plotted onto the map using a customized computer program.

Results

The analysis of the electronic theodolite data provided detailed information about the movement, spatial patterns and traveling speed of the bottlenose dolphins in the Sado Estuary study area. Here, I summarize the results of 35 tracked sightings, ranging in duration from 1 to 321 min. In 14 of the 35 sightings, the dolphins traveled directionally through the study area, with regular dive intervals of up to 3.5 min., generally as a single, tight group. The theodolite data analysis resulted in a single plot line representing the course the animals followed (Fig. 4). Occasionally, such groups were observed interrupting their directional travel and engaging in a period of erratic movements for up to 145 min. (Fig. 5). Other times, the animals were swimming, temporarily or at all times, in two or more subgroups, whose positions were tracked individually, resulting in two or more measuring points, which were used to calculate the spatial dispersal of the

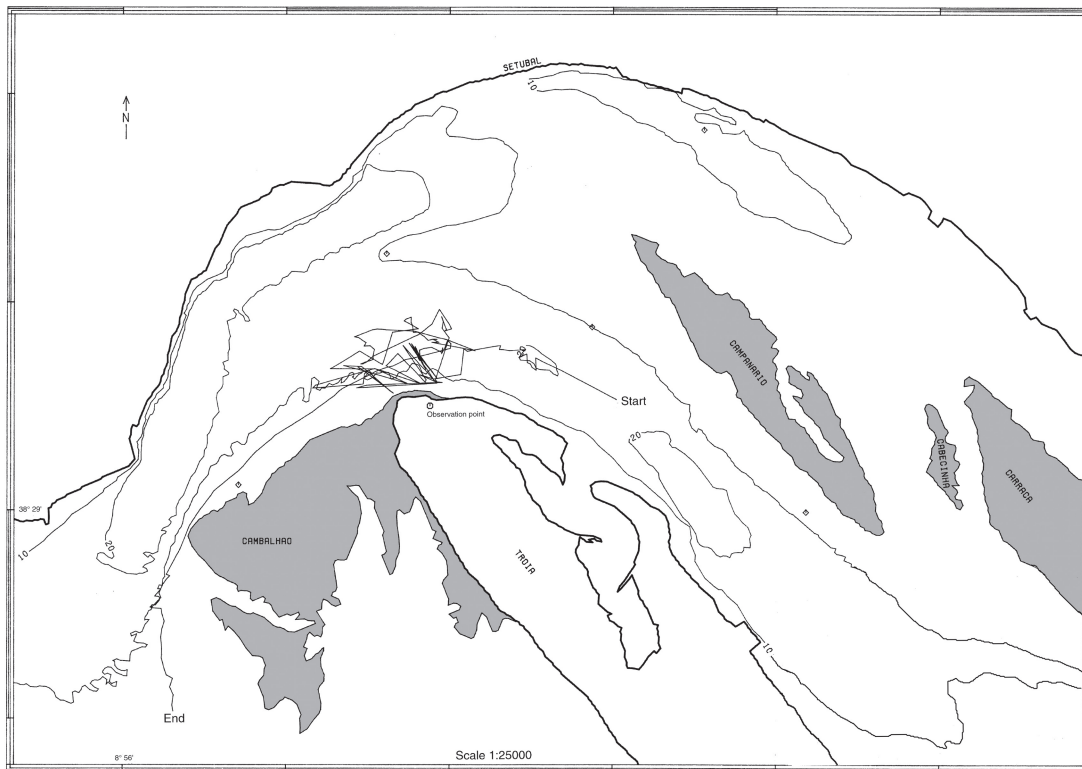


Figure 5. Sample theodolite track of a group of dolphins, moving downstream towards the river mouth, where they engaged in an erratic movement pattern that lasted 145 min, before resuming their directional travel and leaving the estuary. The group was tracked from 9.44 a.m. (start) to 1.14 p.m. (end). Total distance traveled with zigzag swimming excluded was 5975 m.

entire group at a given time (Figs 6, 7). Overall, subgroups were spread-out over an area ranging from 660 to 480 000 m²; however, in 73% of all instances the area comprised less than 45 000 m². The average spatial dispersal for groups of 6–10 animals was about 34 000 m², compared to 64 000 m² for groups comprising 16–20 animals. In waters <10 m deep, the average area covered was 34 000 m², compared to 54 000 m² in waters >10 m.

Dolphins were observed traveling at speeds of up to 3.2 m/s, with an overall average of 1.2 m/s, not considering tidal influence. In only 7% of all instances did they swim faster than 2.2 m/s. In the Sado, groups who transited through the area swam significantly faster (1.4 m/s) than those exhibiting more erratic movements (1.1 m/s), (*t*-test, $P < 0.01$). Swimming speed was also significantly correlated to water depths (*t*-test, $P < 0.01$). In waters less than 10 m deep, the average speed was 1.3 m/s, in those more than 10 m deep the speed was 1.1 m/s.

The directional movement of the Sado dolphins was categorized as upstream, downstream or erratic, the latter referring to dolphins frequently

changing their direction of movement, often unpredictably. There was no significant difference in swimming speed between animals swimming upstream or downstream. In relation to time-of-day, the Sado dolphins swam upstream significantly more often during the morning hours than throughout the afternoon (Kruskal–Wallis H-test, $P < 0.01$). Upstream swimming reached its maximum from 1000 to 1100 h and significantly decreased after 2 p.m. (Mann–Whitney U-test, $P < 0.01$). The animals swam downstream significantly more often during the late morning and early afternoon hours (Kruskal–Wallis H-test, $P < 0.01$), and showed a significant increase from 11 to 12 h to 1–2 p.m. when upstream swimming was already in decline (Mann–Whitney U-test, $P < 0.01$). Dolphins exhibited significantly more erratic movements in the morning than in the afternoon hours (Kruskal–Wallis H-test, $P < 0.01$) with a peak around midday.

In relation to the tidal currents, the Sado dolphins swam significantly more upstream during the first hour of flood tide, than at any other time (Kruskal–Wallis H-test, $P < 0.01$). Downstream and

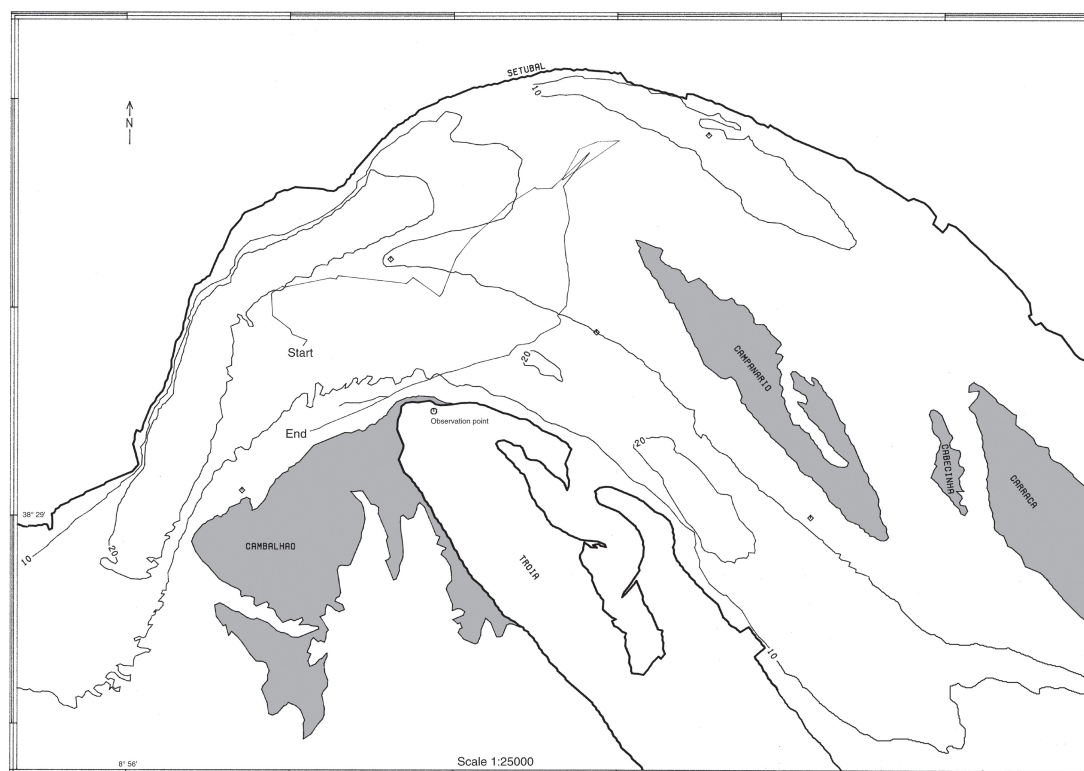


Figure 6. Sample theodolite track of a group of dolphins entering the estuary as a single group, which split into four subgroups and engaged in what appeared to be foraging before rejoining into a single group, swimming towards the river mouth. The group was tracked from 7.29 a.m. (start) to 11.28 a.m. (end). Total distance travelled with zigzag swimming excluded was 8175 m.

erratic movements had no significant correlations with the tides (Kruskal–Wallis H-test, $P > 0.05$). However, the dolphins engaged most frequently in swimming downstream 2 h before and 2 h after high tide, and moved more erratically during flood tide than during ebb tide hours. Generally, the dolphins swam more with, than against, the currents.

Discussion

The Sado Estuary provides a sheltered habitat, with water in some locations 3–5°C warmer than in the river mouth or coastal waters, and a great variety of prey, including a great abundance of mullet and cuttlefish, but also anchovy, bass, eel, octopus, and squid. The Sado dolphins are known to hunt mullets, either alone or in small groups, occasionally driving them onto the sandbanks or the shore, similar to a behaviour reported from other locations (Hoese, 1971). The behavioural data suggest that the process of splitting and rejoining of individual animals or sub-groups is almost always related to foraging activity. The animals disperse

when in search of food, or when they encounter prey and actually start feeding. During such episodes, the subgroups remain structured, but are spread-out, and only converge back into a larger group once the feeding bout ends. Foraging for widely scattered and unpredictable prey might be more successful when carried-out in subgroups separated by greater distances. This explanation is supported by the finding that the total surface area used by these sub-groups correlates with the number of dolphins present, and that, in general, single tight groups transit through the area without exhibiting any foraging behaviour. The adaptation of the dolphin's foraging strategies might therefore primarily determine the group size and structure, with the total area covered being a function of these social parameters.

The observed overall average swimming speed of 1.2 m/s is comparable to the 1.7 m/s and the 0.6–1.4 m/s reported for bottlenose dolphins in Argentina (Würsig & Würsig, 1979) and Sarasota (Irvine *et al.*, 1981). In contrast to the findings of this study, Würsig & Würsig (1979) found that the

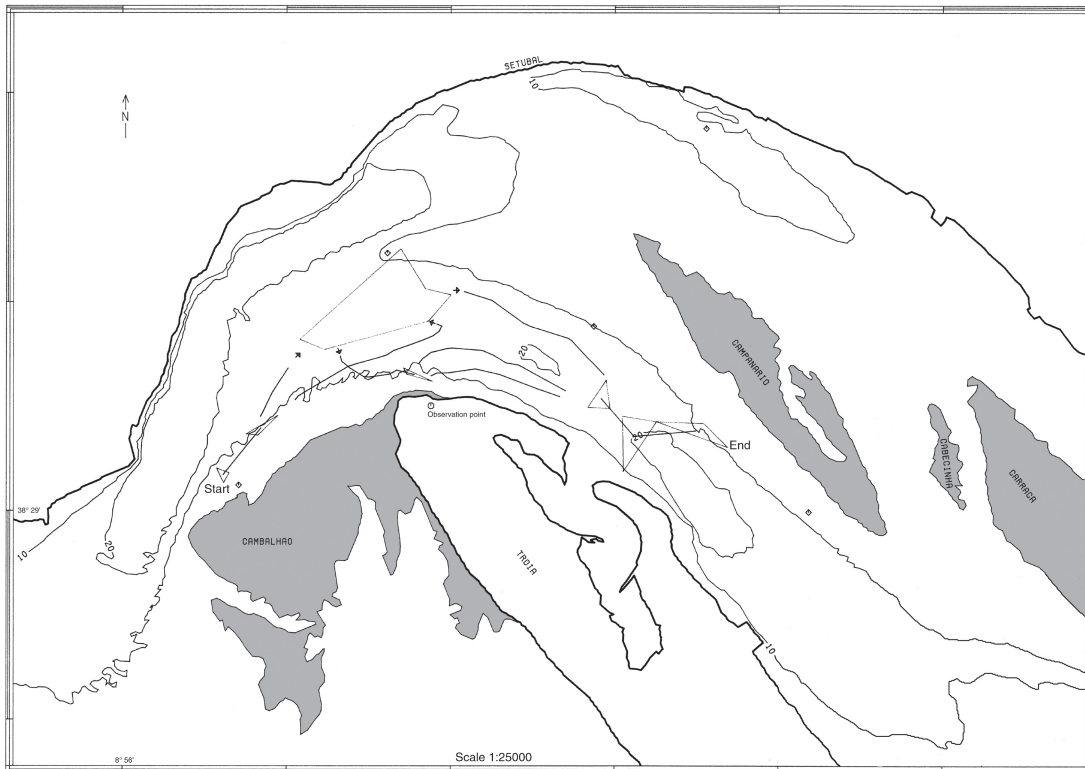


Figure 7. Sample theodolite track of a group of dolphins entering the estuary swimming in three subgroups, interrupted by a period of foraging split up in smaller units. The group was tracked from 1.00 p.m. (start) to 2.20 p.m. (end). Total distance travelled with zigzag swimming excluded was 5050 m.

bottlenose dolphins in Argentina swam more than twice as fast in waters >10 m than in those <10 m (3.9 m/s and 1.6 m/s, respectively). These differences may be related to habitat type and predation risk: an open shoreline found in Argentina compared to the protected estuary of the Sado river.

Time of day is reported to influence the direction of movement of bottlenose dolphins in other areas as well. Würsig & Würsig (1979) observed dolphins in Argentina moving into deep waters during midday where they engaged in feeding. In Port Aransas, Texas, dolphin's movement was correlated with time of day, in some sub-areas more than in others (Shane, 1980). In two such sub-areas, time of day was more influential than tide on swimming direction, with the animals moving northward early in the day, all different directions at midday and southward late in the day (Shane, 1980).

There are several examples, reported in the literature, where tidal current are correlated with the movement pattern of bottlenose dolphin groups. Irvine *et al.* (1981) and Würsig & Würsig (1979) observed dolphins swimming with the current, while Shane (1980, 1987), Gruber (1981), and

Acevedo (1991) registered more movement against the tides. Felix (1994) found no correlation of dolphin movements with the tidal cycle. Tidal currents can affect bottlenose dolphin behaviour directly or indirectly: they can reduce or increase the energy used while swimming and/or influence the movement of prey organisms (Shane, 1987). The tidal currents probably affect the schooling and massing of fish and other prey species, such as squid, with the flood tide causing an inshore shift, and ebb tide causing an offshore shift. Certain inshore-offshore movements of dolphins, as reported by Würsig & Würsig (1977) and Lear & Bryden (1980), may be related to such prey movement as well. Consequently, swimming with or against the tidal currents has been most commonly interpreted in relation to foraging activities (Würsig & Würsig, 1979; Shane, 1980, 1987).

The observed movement and activity patterns suggest that the Sado Estuary serves as an important feeding ground for bottlenose dolphins, and thus represents an integral part of a larger home range. The use of a land-based theodolite proved an excellent tool to track and analyze the movement

patterns and spatial distribution of dolphins without disturbing the natural behaviour of the animals.

Acknowledgments

This research was made possible by Banco Totta e Açores, Coleções Philae, CTT, Grundig, Grupo Espírito Santo, IBM, Inapa, Kodak, Lufthansa, Novotel, Sapec, and Siemens. Local support was provided by Club Naval de Setúbal and Clube Náutico de Troia, and the Naval authority of Setúbal. I am especially grateful to all volunteers who helped with the data collection, and Christoph Nahrung who graciously supported the computer-based data analysis.

Finally, I wish to thank Dave Goodson, Roger Mayo, Barbara J. Brunnick, and two anonymous reviewers for their invaluable comments and critiques of the manuscript.

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