Aquatic Mammals 1998, **24.3**, 117–128

Habitat use by the bottlenose dolphin (*Tursiops truncatus*) in the Sado estuary, Portugal

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Abstract

The habitat use of bottlenose dolphins (*Tursiops truncatus*) in the Sado estuary, Portugal (38°29′N, 08°55′W) was studied throughout two periods (June to August 1986–87; May to December 1992–93). Land and boat based observations were conducted, and theodolite tracking and compass triangulation employed, to determine the position of the animals within the study area.

Seven ecologically distinct areas, including open ocean, shallow coastal waters, channel areas and shallow waters inside the estuary, were surveyed in this study. Differences were attributed to water depth, water temperature, currents, abundance of prey and levels of pollution (agricultural, industrial and urban waste water runoffs).

The dolphins appear to come into the Sado estuary most often during the morning hours and with flood tide, swimming inward through the southern canal zone and foraging with the current. They may remain in this sub-area or extend their distribution to other sub-areas during morning hours. In the early afternoon, the animals can be frequently observed in either the southern canal zone, the ship channel or the outside shallows, foraging, traveling or exhibiting non-directional movement. With the beginning of ebb tide, and through the hours of late afternoon, the dolphins gradually move towards the ship channel and the outside shallows, moving progressively downstream and eventually leaving the study area. During this slow exodus, the animals continue to forage, participate in social interaction or non-directional movements.

Introduction

During the last 20 years, coastal populations of bottlenose dolphins (*Tursiops truncatus*) have been studied in many areas around the world. Teixeira (1979) and Hussenot (1982) were the first to report on bottlenose dolphins inhabiting the Sado estuary of Portugal and its adjacent waters. A preliminary series of surveys conducted by d.Santos and Lacerda (1987) showed that this area was particularly suitable for an in-depth study of individual dolphins, their social organization, behavior patterns and ecology.

The present study aims to contribute to a better understanding of bottlenose dolphin populations inhabiting estuarine and adjacent coastal areas, which are high in biological productivity and human impact. The Sado estuary provides a sheltered habitat with the advantages of a continuous food supply, and low predation pressure. There is currently growing concern about habitat loss and degradation, which could potentially lead to a decline in food quality and quantity.

In this paper I document the patterns of habitat use by the only resident bottlenose dolphin community in coastal Portuguese waters.

Methods

The study area

The study area is centered on the estuary of the Sado river, which joins the Atlantic Ocean on the west coast of Portugal, near the city of Setúbal. The river mouth is narrow, with a 2 km span, and is located at approximately 38°29′N, 08°55′W. Situated south of the Bay of Setúbal, the long, sandy and narrow peninsula of Tróia is fed by the south-north littoral drift, providing shelter to the inner part of the estuary and its northern shore (Fig. 1). The study area, comprising about 150 km^2 in total, also includes adjacent waters to the west near Arrábida, characterized by a rocky shoreline, and the open sandy beaches of the Tróia Peninsula, to the south-west. Tidal amplitudes range to 3.5 m and their effect may be felt 50 km upstream.

In the late 1970s, it became clear that the Sado estuary was an important development and nursery area for a variety of organisms, including fish species such as anchovy, sole and rays (Peneda *et al.*, 1980). In order to protect this important source of biological productivity and species

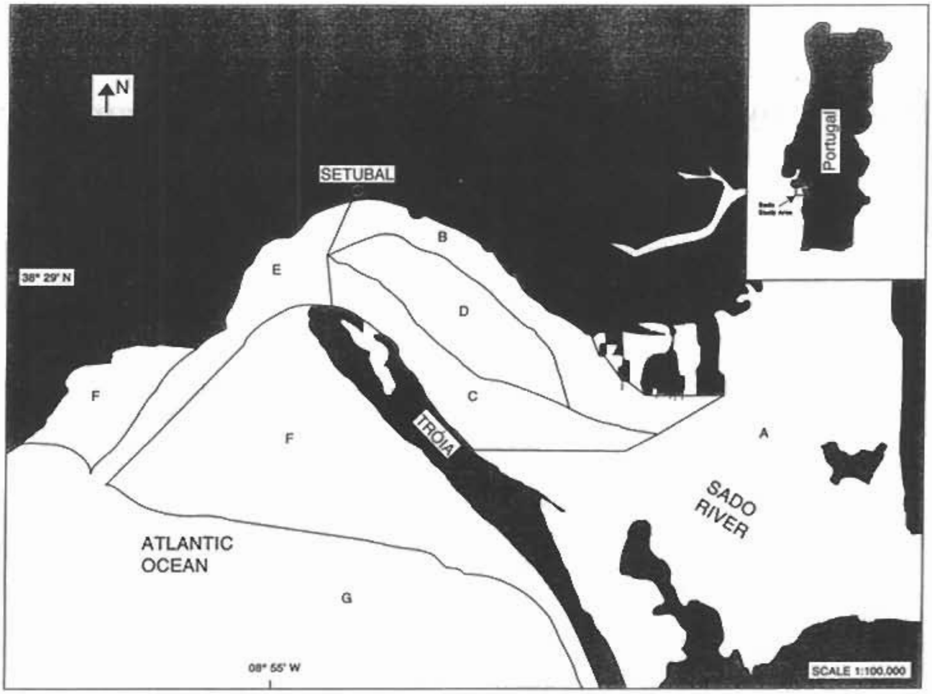

Figure 1. The Sado estuary and the distinction of seven sub-areas.

diversity, a part of the estuary was designated a Nature Reserve in 1980.

Human utilization, and the amount of effluents discharged into the estuary, varies considerably between the northern canal zone and southern canal zone, and also between the estuary and its adjacent waters. As a result, life conditions and resources vary between different locations and times of year. Therefore I divided the study area into seven sub-areas, using geo-physical and ecological characteristics, including information on the degree of pollution due to the discharge of effluents (Fig.1).

Distinction of sub-areas

(A) *Upper estuary shallows* are located on the uppermost reaches of the estuary. Water depth is generally less than 10 m. This is the widest portion of the estuary (5 km).

(B) *Northern canal zone* is bordered to the north by the city of Setúbal, and its industrial area which extends eastward of the city. Water depth varies from less than 5 m to a maximum of 16 m. The majority of all domestic and industrial effluents are discharged into this area.

(C) *Southern canal zone* is located along the eastern side of the Tróia peninsula and continues eastward into the Alcácer channel. The southern canal zone is deeper than the northern canal zone, and exhibits a strong discharge current (Peneda *et al.*, 1980). The water depth exceeds 5 m almost everywhere, with two deep canyons, where the depth reaches over 20 m.

(D) *Midwater shallows* are located between the northern and the southern canal zone, and include sand and mud banks, which are often exposed during low tide. These shallow waters may prevent a fast and free exchange of water and other substances between the northern and southern canal zone.

(E) *Ship channel* is located downstream of the canal zones and mid-water shallows and extends through the river mouth towards the open sea. The depth is greater than 10 m, and exceeds 40 m in the river mouth. All larger vessels entering the harbor of Setúbal, or using the shipyard, must pass through the ship channel into the estuarine waters.

(F) *Outside shallows* are divided by the ship channel into two sections, and are defined by the 10-m contour lines towards the open sea: one part extends from the entrance of the ship channel in a curved line to the north. The southern section follows a long slope to the south, curving in at 38°26'N, 8°53'W and starting to move parallel to shore at about 38°25,1'N, 8°50'W. It is nearly twice the size of the northern section, and also includes a large sandbank, which is sometimes fully exposed during low tide, and situated close to the river mouth. South of 38°25,1'N, 8°50'W, the 10-m line is much closer to the shoreline which experiences a much stronger surf than the other, more protected, areas. Water depth is less than 10 m, often less than 5 m.

(G) *Open sea* is considered the area west of both the ship channel and the outside shallows, beyond the 10-m line.

Materials
Hand-held 7 × 50 Nikon® binoculars were used to search for dolphins and for close-range observations, and the monocular of an electronic theodolite (Zeiss® Eth4) for long-range observations (only from shore). The boat surveys were carried out in an 3.5 m inflatable boat, equipped with a 40 HP outboard engine, or a 5.5 m fiberglass boat, equipped with two 25 HP, or a single 70 HP outboard engine. The observations were recorded using small dictating machines and tape recorders such as the Sony® WM-202, and the UHER® 4000 Monitor.

To determine the position of the animals within the study area I used several techniques, including aligning landmarks, compass bearings and an electronic theodolite (for further details, see Harzen, 1989). In order to reveal exact movement patterns, the theodolite bearings were read every time dolphins came to the surface, while all other location-related data were obtained through scan samples. Although different in their precision, field trials have shown that the potential for error in relation to the chosen sub-areas to be marginal. Therefore, the data obtained from all three techniques were integrated into the overall analysis.

Research effort
After a one month pilot study in May 1986 (which was conducted to define the research methodology), observations were carried out in the months June to August in 1986 and 1987, between May and October 1992 and May and December 1993.

Behavioral measures and sampling
Within the same study I compiled an ethogram of 62 distinct behavioral units which provide the basis to define seven behavioral categories, some of which were further structured into sub-categories (for further details, and how these definitions compare with other studies, see Harzen, 1995).

Travel is characterized as a directional movement, of the dolphins, at various speeds without evidence of any other activity, with the animals clearly being in transit from one area to another. Non-directional movement is defined as a pattern where the global direction may change (occasionally or often), and the dolphins exhibit various surfacing patterns, such as round surfacing, arched dives, pause surfacing and floating. Foraging activity is divided into three sub-categories: directional group feeding, localized group feeding and erratic individual feeding. Directional group feeding is characterized by 6–8 animals swimming in a tight formation and making steep, long dives lasting 3 or more minutes, often surfacing close to the area where they began the dive. During localized group feeding the animals surface in a relatively small area with various orientations. Dives of 30 to 90 seconds are interrupted by excessive surface activity, including various types of leaps, pin-wheeling and the aerial capture of fish. Erratic individual feeding is characterized by small groups or individuals dispersed over a very large area, extending 1 km in all directions. Surfacing patterns are unpredictable. Surface activity includes lunges, leaps, fish tossing and cuttlefish breaking. Sea birds can often be observed above individuals or a group of dolphins, and bird staring by dolphins has been observed as well. Contact behavior is divided into mating, epimeletic behavior (only observed performed by an adult towards a dead calf; see Harzen & d.Santos, 1992), and miscellaneous contact behavior, including all events of an interaction between two animals near or at the surface with no indication of foraging or mating. Maternal care is defined as behavioral sequences in which a calf or juvenile is observed in close association with 1–4 adults which are clearly separated from any other group of dolphins. The animals involved may engage in foraging, non-directional movement or contact behavior. Play refers to the behavioral units of bow-riding, bow-leaping, wave-leaping and surfing. Rest is characterized by a very slow drifting motion of the animal, which may include raising and sinking, without evidence of any other defined behavioral activity.

Statistical analysis
In the course of data analysis, chi-square, Kruskal–Wallis test and Mann–Whitney *U*-test, were employed (Siegel, 1987; SPSS statistical package). A peculiarity is the employment of a so-called intrinsic null-hypothesis in a chi-square test where the expected values used are calculated on the basis of the overall distribution of the observed parameter. The procedure is as follows: for each sub-area one first calculates the percentage of utilization within the overall sub-area budget. The number of total observed cases of the sub-areas in each hour of the day or the tidal cycle, are then multiplied by this percentage, resulting in the expected values for the habitat utilization. The observed and expected values are then entered into the standard formula providing χ^2.

Data were corrected for effort by dividing the sighting time (time spent with dolphins in sight) by the observation time (total time spent looking for dolphins). The results were then corrected for the

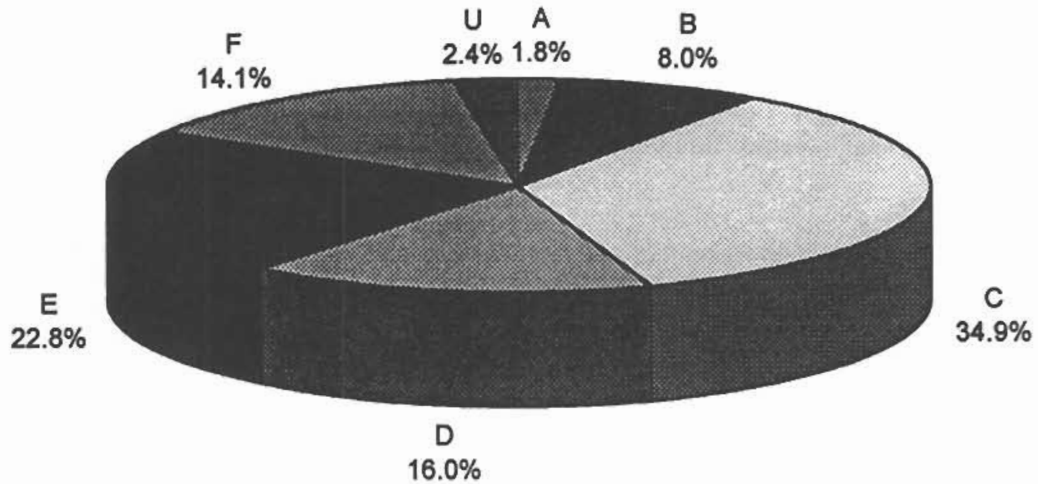

Figure 2. Frequency distribution of the utilisation of defined sub-areas [A—upper estuary shallows, B—northern canal zone, C—southern canal zone, D—mid-water shallows, E—ship channel, F—outside shallows, U—unknown].

different sizes of the defined sub-areas, dividing them by a pre-calculated value representing the proportion of a given sub-area within the overall area size.

Results

A total of 1507 daylight hours were spent in the field, with the majority of observations occurring between 08:00 and 18:00 h. A total of 431.5 hours were spent in direct observation of dolphins, resulting in 307 sightings. Eleven hours (=2.5%) of observations lack any geographical information and are categorized as 'unknown'. This sub-area is excluded from further analysis because no animals were observed in the 'open sea'.

In the following I present the results on the utilization of different sub-areas, the occurrence patterns related to time of day, tidal cycle, and finally the behavior observed in these sub-areas.

Utilization of different sub-areas
The distribution of occurrence is significantly different from random (chi-square test, $P<0.0001$). The overall occurrence in the seven sub-areas (Fig. 2) places the dolphins, most of the time, in the southern canal zone, followed by the ship channel, the mid-water shallows and the outside shallows. The upper estuary shallows and the northern canal zone were only infrequently utilized.

Diel changes in occurrence patterns
Do the dolphins utilize a given area to a different extent throughout the day? The animals were observed, at any given time of the day, during daylight hours, in all areas except for the upper estuary shallows (Fig. 3), where the hourly distribution of occurrence was not different from random (Kruskal–Wallis test, $P>0.05$).

For all other sub-areas (B–F), the hourly distribution of occurrence was significantly different from random (Kruskal–Wallis test, $P<0.0001$).

In the southern canal zone occurrence increases from the early morning and reaches a first peak between 13:00 and 14:00 h (Mann–Whitney *U*-test, $P<0.001$). There is a decrease from 14:00 to 15:00 h (Mann–Whitney *U*-test, $P<0.001$), and an increase again towards the hour of 18:00 to 19:00 (Mann–Whitney *U*-test, $P<0.001$). The difference in time the dolphins spent in the southern canal zone in the early morning (08:00 to 09:00 h), and the early afternoon (13:00 to 14:00 h), is also highly significant (Mann–Whitney *U*-test, $P<0.001$).

The ship channel becomes progressively more frequented throughout the morning and early afternoon hours (Mann–Whitney *U*-test, $P<0.001$) and reaches its maximum between the hours of 17:00 and 18:00 h (Mann–Whitney *U*-test, $P<0.01$), decreasing afterwards (Mann–Whitney *U*-test, $P<0.01$).

The mid-water shallows are more frequented in the morning hours with a steady increase from 08:00 to 12:00 h (Mann–Whitney *U*-test, $P<0.05$). Then there is a decrease ending between 15:00 and 16:00 h (Mann–Whitney *U*-test, $P<0.05$), which in turn is followed by a slight increase in the late afternoon (Mann–Whitney *U*-test, $P<0.05$).

The northern canal zone is particularly frequented throughout the morning hours with an increase from 08:00 to 11:00 h (Mann–Whitney

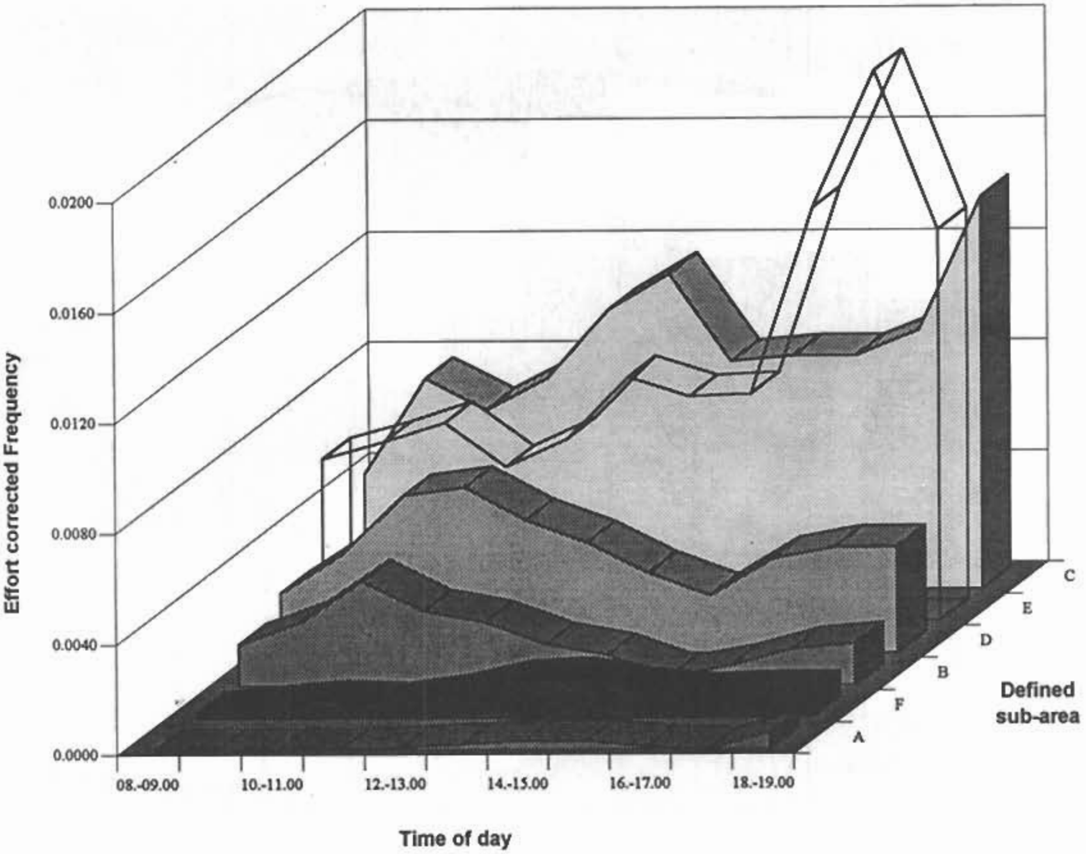

Figure 3. Frequency of occurrence in the defined sub-areas in relation to time of day [A—upper estuary shallows, B—northern canal zone, C—southern canal zone, D—mid-water shallows, E—ship channel, F—outside shallows].

U-test, $P<0.001$), followed by a decrease reaching its minimum between 15:00 and 16:00 h (Mann–Whitney *U*-test, $P<0.001$).

The outside shallows are most often frequented in the early afternoon (Mann–Whitney *U*-test, $P<0.0001$).

A chi-square test with an intrinsic null hypothesis (see above) was used to determine if dolphins utilize a given area preferentially by the hour of the day. The proportions of sub-area utilization were not significantly different from the overall distribution of habitat use (chi-square test, $P>0.05$; see Fig. 4). However, the analysis revealed some trends; the northern canal zone was preferentially used in the hour of 10:00 to 11:00, while the upper estuary shallows were preferred in the hour of 15:00 to 16:00. Finally the mid-water shallows and the outside shallows were preferentially utilized between the hours of 11:00 and 12:00, and 14:00 and 15:00, respectively.

Tidal cycles

The analysis revealed that the animals were observed, at any time of the tidal cycle, in all areas except for the upper estuary shallows (Fig. 5). However, the distribution of occurrence in the upper estuary shallows was significantly different from random (Kruskal–Wallis test, $P<0.01$). This area was most frequented in the sixth hour of flood, and the first hour of ebb tide, which are the two hours with the highest water level in the estuary, with a significant increase before high tide, and a significant decrease afterwards (Mann–Whitney *U*-test, $P<0.05$).

The distribution of occurrence, in relation to the tidal cycle, was also significantly different from random in the southern canal zone and the mid water shallows (Kruskal–Wallis test, $P<0.01$).

In the southern canal zone, occurrence peaks in the fifth hour of flood tide, followed by a significant decline to the second hour of ebb tide (Mann–

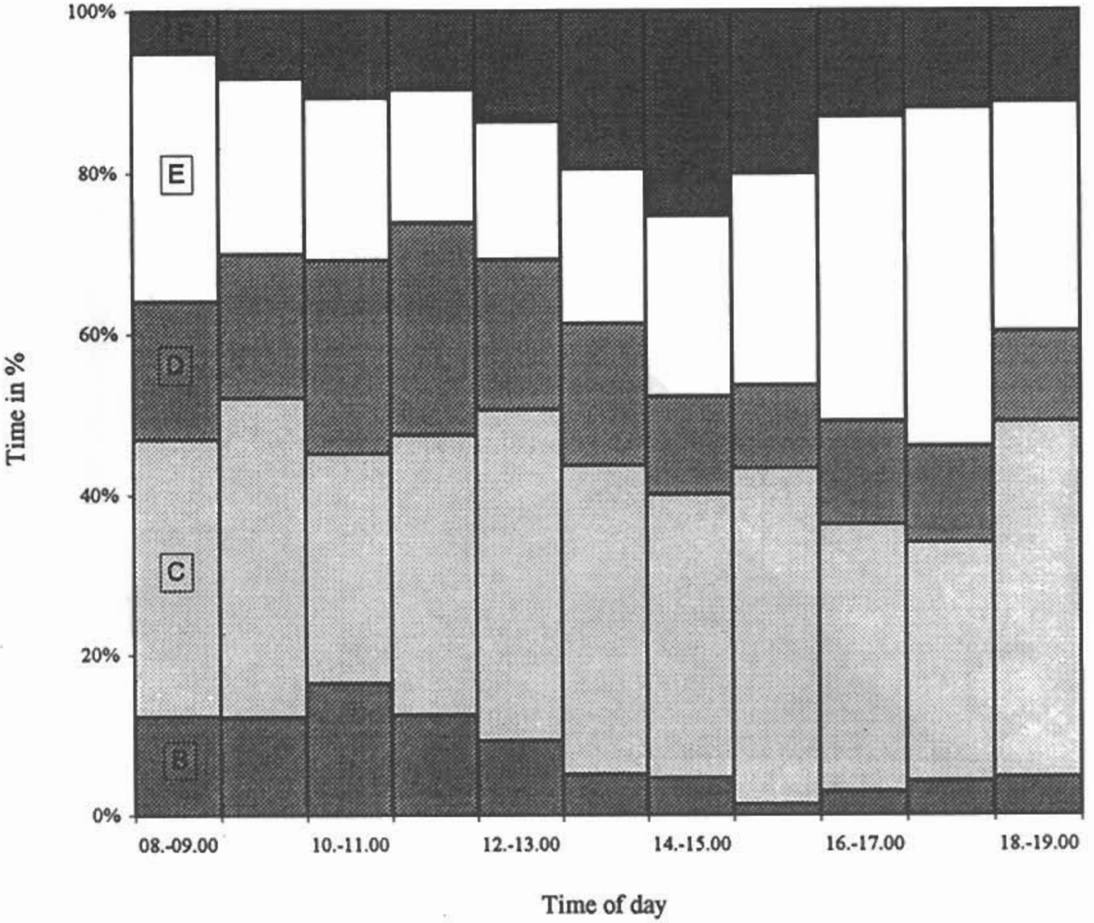

Figure 4. Proportional time budget of the utilisation of five sub-areas in relation to time of day [B—northern canal zone, C—southern canal zone, D—mid-water shallows, E—ship channel, F—outside shallows].

Whitney *U*-test, $P<0.01$), which continues to the fifth hour of ebb tide. In the mid-water shallows, the decline from the first to the third hour of flood tide proves to be significant (Mann–Whitney *U*-test, $P<0.05$), as does the increase from the third to the sixth hour of ebb tide (Mann–Whitney *U*-test, $P<0.05$).

For all other sub-areas no significant differences could be found (Kruskal–Wallis test, $P>0.05$).

A chi-square test with an intrinsic null hypothesis (see above) was used to determine if dolphins utilize a given area preferentially by the hour of the tidal cycle. The proportions of sub-area utilization were not significantly different from the overall distribution of habitat use (chi-square test, $P>0.05$; Fig. 6).

Behavior

Are sub-areas given preference for certain activities? Play and rest have been observed so infrequently (only 0.3 and 0.2% of the overall behavior frequency distribution, respectively) that I excluded them from the analyses. Contact behavior and maternal care are grouped together into a category called 'social-interaction' (Fig. 7). The proportions of activity patterns observed were significantly different from the overall distribution in the northern canal zone and the ship channel only (chi-square test, $P<0.05$). In the northern canal zone, foraging, social interactions and non-directional movement were observed proportionally more often, while travel and foraging occurred in proportion more frequently in the ship channel.

Discussion

Dolphins appear to come into the Sado estuary predominantly throughout the morning hours with the flood tide. They commonly enter through the

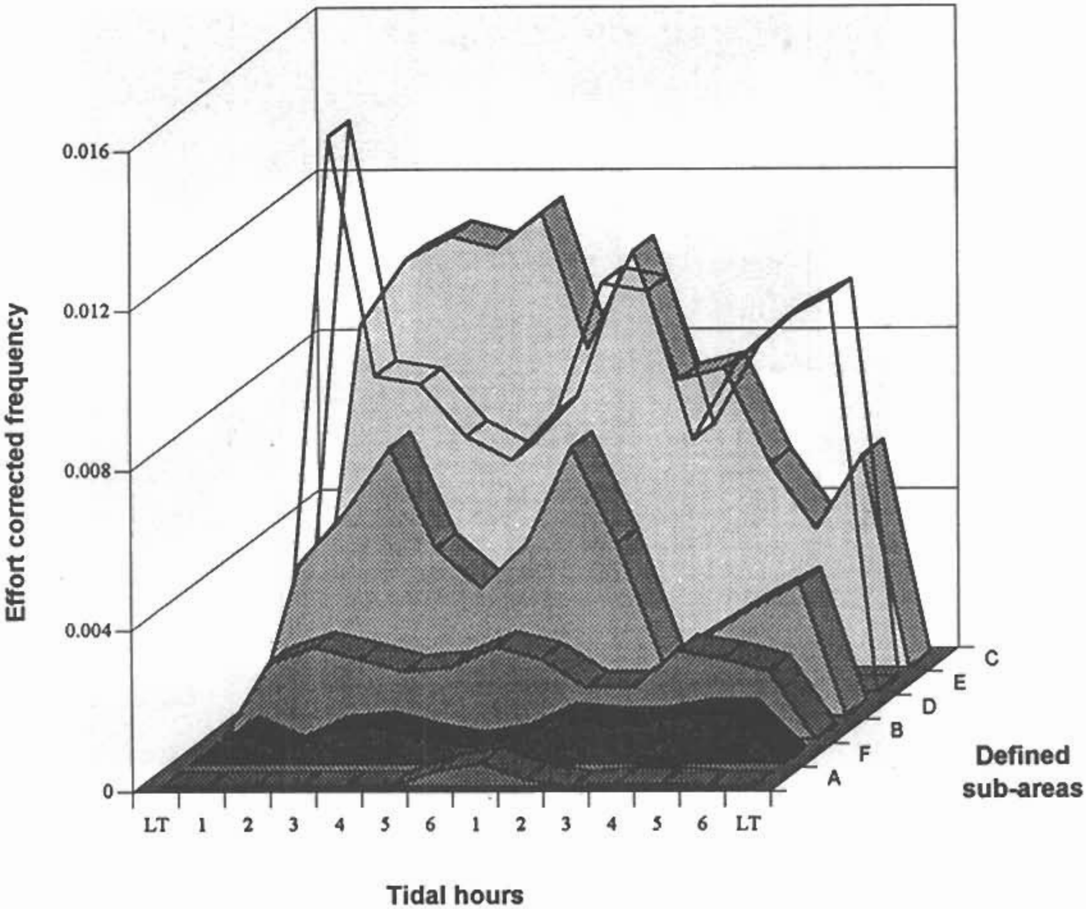

Figure 5. Frequency of occurrence in the defined sub-areas in relation to tidal cycle [A—upper estuary shallows, B—northern canal zone, C—southern canal zone, D—mid-water shallows, E—ship channel, F—outside shallows].

southern canal zone and the ship channel. They appear to commence foraging with the current, remaining in these sub-areas and/or extending their distribution to the mid-water shallows and occasionally the northern canal zone and upper estuary shallows. Significant differences in the distribution of activity patterns were observed only in the northern canal zone, with proportionally less travel, and in the ship channel with relatively more travel and foraging. In the early afternoon, at a time when foraging is still very close to its maximum, and non-directional movement and travel reach their peaks, the animals can be predominantly encountered in the southern canal zone and the ship channel. With the beginning of ebb tide, and in the hours of late afternoon, the dolphins gradually leave the southern canal zone and mid-water shallows towards the ship channel, and to a lesser extent the outside shallows, moving more and more downstream and eventually leaving the study area. During this slow exodus, the animals continue to engage in foraging, non-directional movement, and occasionally in contact behavior.

Diel cycle

Except for the upper estuary shallows, all sub-areas were utilized to a significantly different extent throughout the daylight hours in the Sado estuary. In the southern canal zone dolphins were most frequently seen from noon to early afternoon, at the time when upstream swimming and erratic swimming were around their maxima, and then again in the late afternoon (6–7 p.m.). The ship channel was increasingly utilized throughout the day, reaching its maximum at 5–6 p.m. The midwater shallows, which are predominantly frequented when foraging, were used significantly more in the morning (when more erratic swimming was also observed), than in the afternoon hours. The pattern in the northern canal zone was very similar. Finally, dolphins were

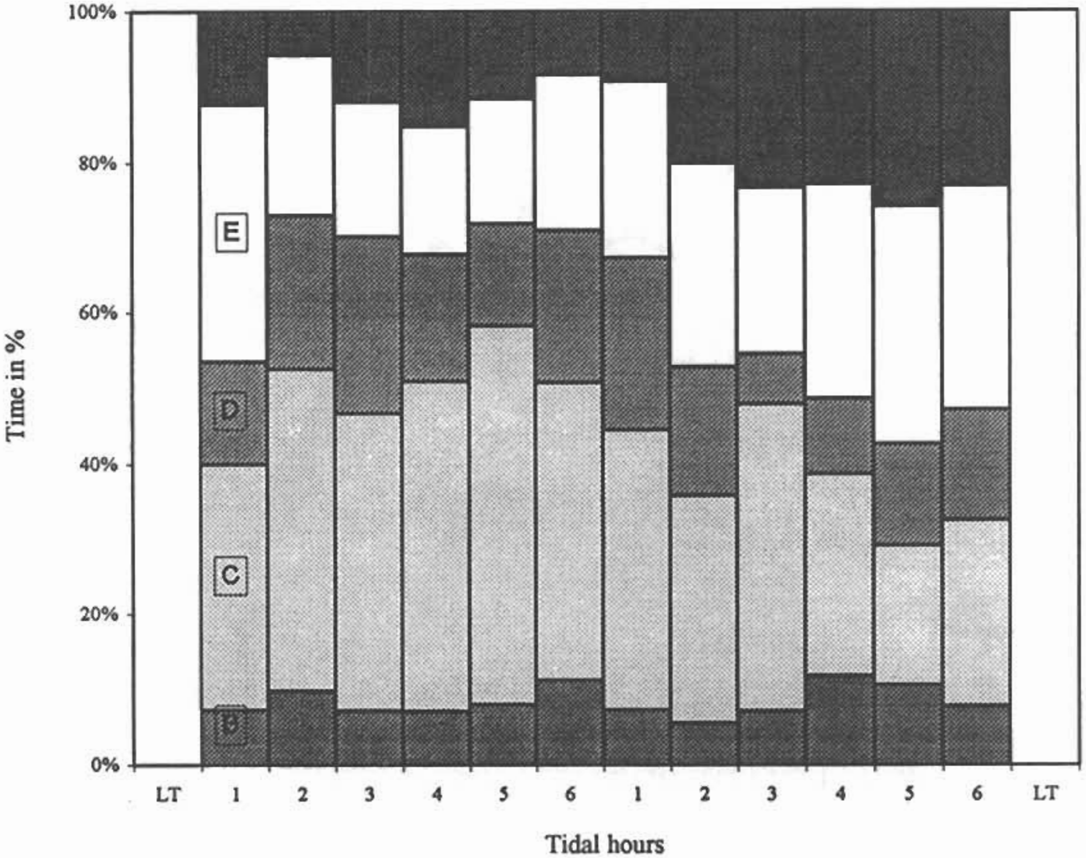

Figure 6. Proportional time budget of the utilisation of five sub-areas in relation to the tidal cycle [B—northern canal zone, C—southern canal zone, D—mid-water shallows, E—ship channel, F—outside shallows].

most frequently seen in the outside shallows throughout the afternoon hours, when downstream swimming was also prevalent.

Tidal cycle

In relation to the tidal cycle, only the southern canal zone, the mid-water shallows, and the upper estuary shallows were utilized to a significantly different extent during the daylight hours. In both the southern canal zone and the mid-water shallows, dolphins were observed predominantly during the hours of flood tide. This coincides with the distribution of foraging behavior, and to a lesser extent non-directional movement, which were much more frequently observed during the hours of flood tide as well. During the same time period, upstream swimming was more dominant than at any other time, suggesting that dolphins were foraging with the current in both the southern canal zone and the mid-water shallows. Erratic swimming, which is related to foraging, was also more frequent during flood tide hours. In the upper estuary shallows, dolphins were only observed around the hour of high tide, when water depth is the greatest, and when they can move into areas not accessible at any other given time.

Many studies have revealed short-term movements of bottlenose dolphins that are probably associated with a variety of factors, such as the tidal cycle and diurnal cycle of the prey. Saayman & Tayler (1973) noted that the 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 the dolphins moved into deeper water during mid-day hours, where they engaged in feeding and other behaviors at different depths. Lear & Bryden (1980) suspected the animals sought shelter near shore to avoid rough waters offshore during storms.

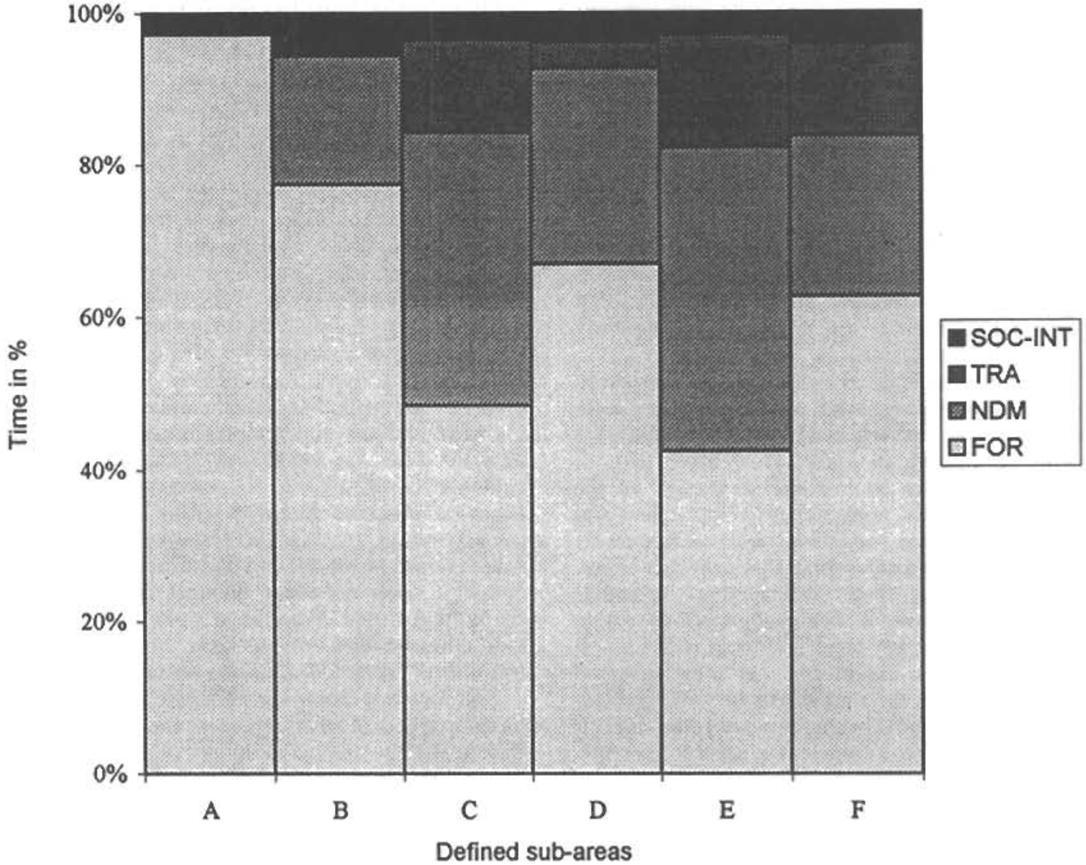

Figure 7. Proportional time budget for four activity patterns in relation to the defined sub-areas [FOR—foraging, NDM—non-directional movement, TRA—travel, SOC-INT—social interaction].

The tidal current often affects short term movements of dolphins. Near Sarasota, Florida, dolphins moved onto shallow seagrass flats with the incoming tide where they were observed feeding (probably on mullet) in small groups (Irvine & Wells, 1972; Wells *et al.*, 1980; Irvine *et al.*, 1981). In Aransas Pass, Texas, dolphins were observed stationing themselves against the tide, a behavior that was first related to 'resting' (Shane, 1977; 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, True (1885), Gunter (1942), Irvine & Wells (1972) and Würsig & Würsig (1979) reported on movement with the tides, and Leatherwood (1979) and Felix (1994) found no significant correlation between the movement of the dolphins and the tidal current.

Behavior

The obvious preference of the Sado dolphins for some sub-areas, in particular the southern canal zone and the ship channel (close to the peninsula of Tróia) is consistent with other observations (Freitas and d.Santos, 1996). The preference for these areas, compared to the northern canal zone, appears to have biological as well as geophysical grounds, since the south channel is deeper, less polluted and the current is faster. A third of all foraging behavior occurred in the southern canal zone, suggesting that prey may be either very abundant, or easier to catch in that area. Dolphins were also commonly seen chasing mullet against the shore on the edge of Cambalhão, a sand bank situated at the river mouth (ship channel/outside shallows). Shallow water feeding, characterized by a rapid chase terminating with a sudden turn or pinwheel, had been previously reported by d.Santos & Lacerda (1987), and also been observed in other study areas, including Sarasota, Florida, with similar patterns, (Irvine *et al.*, 1981).

The Sado dolphins exhibit some preferences in the utilization of the study area, however only in the ship channel were all seven behavioral activities observed. In the southern canal zone and the outside shallows all activities, except resting, were observed. In the mid-water shallows, all behaviors were observed except for play and resting, while in the remaining two sub-areas the dolphins engaged only in foraging, non-directional-movement, contact behavior and maternal care (northern canal zone), foraging, and contact behavior (upper estuary shallows). Only foraging and contact behavior were observed in all areas. Furthermore, foraging was the most prominent activity, even in the upper estuary shallows and the northern canal zone, which underlines the importance of the study area as a feeding ground.

During the majority of time spent foraging, non-directional movement and travel, dolphins were found in the southern canal zone and the ship channel, indicating they used these areas to both enter and exit the estuary and to forage. In the mid-water shallows, non-directional movement and travel were reduced, while foraging was frequently observed. This indicates that this sub-area represents another preferred feeding area. A similar situation is observed for the outside shallows, where foraging is by far the most dominant activity. All behavior patterns, except for rest, were observed most frequently in the southern canal zone, indicating that this may be the most beneficial and important sub-area for the dolphins within the entire study area.

Hanson & Defran (1993) divided the San Diego study area into six habitat types, including *offshore*, defined as an area between 0.25 and 0.5 km from shore, *estuary*, *reef*, *sand*, *kelp border* and *ocean border*. They found that the dolphins spent about 90% of their time in nearshore areas within 0.25 km from shore.

In the same study they analyzed the effect of offshore border type (kelp and ocean) and nearshore habitat type (estuary, reef and sand) in relation to feeding, traveling and socializing. They observed more feeding and less traveling in ocean border areas, and more feeding in reef and estuary areas than in sand areas near shore. They argued that tidal currents and different prey species in the distinct habitat types are most probably responsible for the differences in the activity patterns.

A correlation between activity patterns and habitat characteristics has also been reported by Shane (1987). She had divided the study area at Sanibel into 18 sub-areas, which she described ecologically. Feeding was most frequently observed in areas with strong currents and with abundant seagrass and mangroves. She noted that the Sanibel dolphins exhibited most socializing behavior in areas with heavy boat traffic, a finding she could not really explain, and which was in contrast to observations in Aransas Pass, Texas, where dolphins socialized most frequently in areas free from heavy boat traffic. She concluded, that the animals were able to discriminate between areas of different ecological structure and would use these sub-areas appropriately (Shane, 1987). Acevedo (1991) studied the bottlenose dolphins in the entrance to Ensenada de la Paz, Mexico, and reported a different use of sub-areas within the study area. The Mexican dolphins spent most of their time in the mouth region, which includes their favorite feeding location. Two other preferred feeding areas were located in distant regions of the study area, to and from which the dolphins traveled along well defined routes. Further evidence for distinct habitat use comes from a study of bottlenose dolphins in the Gulf of California, Mexico (Ballance, 1992). Sighting rates and the number of schools were highest in areas near the mouths of estuaries. Foraging behavior constituted 61%, traveling 22% of all behavior observed in areas within 5.5 km of an estuary mouth. In areas farther away, the behavior was reversed, with 23% of the time spent feeding and 61% spent traveling. Ballance concluded that the dolphins used estuarine areas to feed and that high concentrations of nutrients, zooplancton and fish attract bottlenose dolphins to such areas.

Last but not least, the different use of certain habitat types is also reported in other species, specifically the spinner dolphins of Hawaii. These animals rest during the day in sheltered bays and feed during the night on the deep scattering layer offshore (Norris & Dohl, 1980).

The Sado dolphin community consists of an estimated 40 to 50 animals, of which only 25 were encountered in both study periods (for details on the social structure of the Sado community see Harzen, 1995). High re-sighting frequencies over the years indicate that these animals are long term residents in the 150 km^2 study area, which may represent only part of a possible larger home range, an estimate of which can be obtained by correlating the average traveling speed with the time between two sightings of the same animals. As a result, the area in which the Sado-dolphin community should be encountered most often, if not exclusively, can therefore be described as a large triangle, reaching south from Setúbal to Sines, and west to the area around Cabo Espichel, which amounts to approximately 1200 km^2.

Considering the habitat utilization on an individual basis, almost equal percentages of individuals were seen predominantly in either southern canal zone, the midwater shallows, or the ship channel. Only 10% (n=4) of the individual dolphins inhabiting the study area, at the end of the study period, were seen most often in the outside shallows, and none were encountered in the upper estuary shallows or the northern canal zone. The majority of animals, who are considered members of the core group, were encountered the farthest upstream, while the others remained closer to the river mouth. This indicates that the dolphins of this community may have different, partly overlapping home ranges.

A similar finding is reported from Sanibel, Florida, where dolphins exhibited a clear fidelity to particular portions of the study area. About 50% were encountered only in the bay, while approximately 25% of the individuals inhabited the Gulf of Mexico and an equal 25% inhabited the Gulf and the bay (Shane, 1987). Studying bottlenose dolphins in southern Texas, Shane (1980) found that the animals concentrated their activities in certain specific areas. She defined three home ranges shared by several individuals, some of which used these ranges seasonally, others year-round. The concept that differences in habitat utilization can be expressed through different home ranges is also supported by the long-term study of bottlenose dolphins in Sarasota, Florida (Irvine & Wells, 1972; Wells *et al.*, 1980; Irvine *et al.*, 1981), where different age and sex classes apparently occupied different home ranges.

These results, and their comparison with studies of bottlenose dolphin populations in an open coastline habitat, suggest that site fidelity is indeed related to habitat differences. Larger estuaries and estuarine systems provide sufficient nutrient resources to maintain a resident dolphin community, while smaller estuaries and open coastline habitats, with patchy and more ephemeral distribution of prey, forces the animals to move from one food source to the next.

Acknowledgments

This research was made possible by Banco Totta e Açores, Colecções 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 Nautico de Tróia, the Naval authority of Setúbal. I am grateful to all volunteers who helped in the various stages of the data collection.

I wish to thank Nélio Barros, Barbara J. Brunnick, Dan Odell and Randy Wells for their invaluable comments and critiques of the manuscript.

References

Acevedo, A. (1991) Behaviour and movements of bottlenose dolphins, *Tursiops truncatus*, in the entrance to Ensenada De La Paz, Mexico. *Aquatic Mammals* **17**(3), 137–147.

Ballance, L. T. (1992) Habitat use patterns and ranges of the bottlenose dolphin in the Gulf of California, Mexico. *Marine Mammal Science* **8**(3), 262–274.

d.Santos, M. E. & Lacerda, M. (1987) Preliminary observations of the bottlenose dolphin (*Tursiops truncatus*) in the Sado estuary, Portugal. *Aquatic Mammals* **13**(2), 65–80.

Felix, F. (1994) Ecology of the coastal bottlenose dolphin *Tursiops truncatus* in the Gulf of Guayaquil, Ecuador. In: G. Pilleri (ed.) *Investigations on Cetacea*, Vol. XXV, pp. 235–256.

Freitas, A. & d.Santos, M. E. (1996) A study of habitat use by bottlenose dolphins in the Sado estuary, Portugal. *Abstract. Tenth Annual Conference of the European Cetacean Society*, March 11–13 1996, Lisbon, Portugal. p. 13.

Gruber, J. A. (1981) Ecology of the Atlantic bottlenosed dolphin (*Tursiops truncatus*) in the Pass Cavallo area of Matagorda Bay, Texas. Master's Thesis, Texas A & M University.

Gunter, G. (1942) Contributions to the natural history of the bottle-nose dolphin, *Tursiops truncatus* (Montagu), on the Texas coast, with particular reference to food habits. *Journal of Mammalogy* **23**, 267–276.

Hanson, M. T. & DeFran, R. H. (1993) The behavior and feeding ecology of the Pacific coast bottlenose dolphin, *Tursiops truncatus*. *Aquatic Mammals* **19**(3), 127–142.

Harzen, S. (1989) Zum Vorkommen und zur raumzeitlichen Aktivität des Grossen Tümmlers, *Tursiops truncatus* (Montagu, 1821) im Mündungsgebiet des Sado, Portugal. Master's Thesis, University of Bielefeld, Germany.

Harzen, S. (1995) Behaviour and Social Ecology of the Bottlenose dolphin, *Tursiops truncatus* (Montagu, 1821) in the Sado estuary. Ph.D. Dissertation, University of Bielefeld, Germany.

Harzen, S. & d.Santos, M. E. (1992) Three encounters with wild bottlenose dolphins (*Tursiops truncatus*) carrying dead calves. *Aquatic Mammals* **18**(2), 49–55.

Hussenot, E. (1980) Le grand dauphin *Tursiops* truncatus en Bretagne: types de frequentation. *Penn ar Bed (Brest)* **12**(103), 355–380.

Irvine, A. B., Scott, M. D., Wells, R. S. & Kaufmann, J. H. (1981) Movement and activities of the Atlantic bottlenose dolphin, *Tursiops truncatus*, near Sarasota, Florida. *Fishery Bulletin US* **79**(4), 671–688.

Irvine, B. & Wells, R. S. (1972) Results of attempts to tag Atlantic bottlenosed dolphins (*Tursiops truncatus*). *Cetology* **13**, 1–5.

Lear, R. J. & Bryden, M. M. (1980) A Study of the Bottlenose Dolphin *Tursiops truncatus* in Eastern Australian Waters. *Australian National Parks and Wildlife Service Canberra*, Occasional Paper (4).

Leatherwood, S. (1979) Aerial survey of the bottlenose dolphin, *Tursiops truncatus*, and the West Indian Manatee, *Trichechus manatus*, in the Indian and Banana Rivers, Florida. *Fishery Bulletin US* **77**, 47–59.

Norris, K. S. & Dohl, T. P. (1980*a*) Behavior of the Hawaiian Spinner Dolphin, *Stenella longirostris*. *Fishery Bulletin US* **77**(4), 821–849.

Peneda, M. C., Cruces, M. M., Biscaya, J. L. & Santos, M. C. (1980) Preliminary evaluation of physicochemical and biological data collected during a yearly cycle in the Sado estuary. In: *Seminario sobre 'Problemas actuais de Oceanografia em Portugal'*, JNICT, Lisboa, 1980.

Rawson, A. J., Anderson, H. F. & Patton, G. W. (1991) Anthracosis in the Atlantic bottlenose dolphin (*Tursiops truncatus*). *Marine Mammal Science* **7**(4), 413–416.

Saayman, G. S. & Tayler, C. K. (1973) Social organization of inshore dolphins (*Tursiops aduncus* and *Sousa*) in the Indian Ocean. *Journal of Mammalogy* **54**(4), 993–996.

Shane, S. H. (1977) The population biology of the Atlantic bottlenose dolphin, *Tursiops truncatus*, in the Aransas Pass area of Texas. M.S. Thesis, Texas A & M University.

Shane, S. H. (1980) Occurrence, movements, and distribution of bottlenose dolphin, *Tursiops truncatus*, in southern Texas. *Fishery Bulletin US* **78**(3), 593–601.

Shane, S. H. (1987) The Behavioral Ecology of the Bottlenose Dolphin. Dissertation Thesis, University of California Santa Cruz.

Shane, S. H. (1990) Behavior and Ecology of the Bottlenose Dolphin at Sanibel Island, Florida. In: S. Leatherwood and R. R. Reeves (eds) *The Bottlenose Dolphin*. pp. 245–265. Academic Press: San Diego.

Shane, S. H., Wells, R. S. & Würsig, B. (1986) Ecology, behavior and social organization of the bottlenose dolphin: a review. *Marine Mammal Science* **2**(1), 34–63.

Siegel, S. (1987) *Nicht-parametrische statistische Methoden.* 3rd ed. Vol. 4. Frankfurt/Main. Fachbuchhandlung für Psychologie GmbH.

Teixeira, A. M. (1979) *Algumas notas sobre os mamíferos marinhos da Costa Portuguesa.* Cascais, Portugal Museu do Mar.

True, F. W. (1885) The bottle-nose dolphin, *Tursiops tursio*, as seen at Cape May, New Jersey. *Science* **5**, 338–339.

Vale, C. & Sundby, B. (1980) A survey of the elemental composition of bottom sediments in the Sado estuary. In *Seminário sobre 'Problemas actuais de Oceanografia em Portugal.* Lisbon, Portugal. JNICT.

Wells, R. S., Irvine, A. B. & Scott, M. D. (1980) The social ecology of inshore odontocetes. In: L. M. Herman, (ed.) *Cetacean Behavior*. pp. 263–318. Wiley Interscience: New York.

Würsig, B. & Würsig, M. (1979) Behavior and ecology of bottlenose dolphin, *Tursiops truncatus*, in the South Atlantic. *Fisheries Bulletin, US* **77**, 399–412.