NOVAFCSH
FACULDADE DE CIÊNCIAS SOCIAIS E HUMANAS
UNIVERSIDADE NOVA DE LISBOA

Spatial Pattern of Dolphin Watching in the Sado Estuary

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Trabalho de Projeto
Mestrado em Gestão do Território
na área de especialização em
Deteção Remota e Sistemas de Informação Geográfica

Novembro, 2021

Trabalho de Projeto

apresentado para cumprimento dos requisitos necessários à obtenção do grau de

Mestre em Gestão do Território
na área de especialização em
Deteção Remota e Sistemas de Informação Geográfica

realizado sob a orientação científica de

Prof. Carlos Pereira da Silva
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AGRADECIMENTOS

Agradeço aos Prof. Pereira da Silva, Prof. Rossana Estanqueiro e Dr. Ricardo Mendes pelo aceite na orientação, paciência, considerações e reflexões para o resultado do trabalho, além de tudo o conhecimento transmitido.

A todos os colegas de mestrado que participaram do curso e possibilitaram discussões e trocas de conhecimentos. A todos os professores do curso de Mestrado em Gestão do Território da Universidade Nova de Lisboa pelos ensinamentos. A todos os funcionários administrativos do Departamento de Geografia e Planeamento Regional da Universidade Nova de Lisboa e do núcleo de mestrados.

Agradecimento constante a minha família e amigos por apoiarem e de qualquer forma ajudarem na realização desse trabalho de mestrado.

SPATIAL PATTERN OF DOLPHIN WATCHING IN THE SADO ESTUARY

JÖRN SCHIROK

RESUMO

Este trabalho de projeto mapeia e analisa dados GPS recolhidos de embarcações marítimo turísticas quando estavam em observação ativa dos golfinhos-roazes (*Tursiops truncates*) no estuário do Sado e no oceano Atlântico. O pequeno grupo de 27 golfinhos do estuário do Sado é um dos poucos grupos na Europa que não regista movimentos migratórios, mas tem um habitat permanente. O conjunto de dados inclui 292 pontos de dados, que foram recolhidos em um esforço de observação de 130 horas no total em 22 dias diferentes durante o verão de 2020. A coleção de dados foi influenciada pela pandemia de Covid19. Os resultados de uma análise exploratória de dados mostram que a observação de golfinhos se concentrou no oceano ao longo da península de Tróia no verão de 2020. O número máximo de localizações registadas por dia foram 33. Número elevado de localizações principalmente, mas não sempre, coincidem com densidades altos de barcos, que foram quantificadas por meio de uma estimativa Kernel Density. Os operadores marítimo-turísticos com licença para observação de golfinhos estavam localizados principalmente em profundidades de água até 20 m. A distância de viagem até o porto de origem fica entre cinco e 11 km. Não registámos nenhuma infração sistemática das diretrizes de observação de golfinhos. A estimativa da Kernel Density provou ser uma ferramenta útil para mapear a extensão e intensidade das operações de observação de golfinhos. Os resultados podem ajudar a melhorar a base de informações para a definição de uma capacidade de carga adequada da população de golfinhos do estuário. Concluímos que a capacidade de carga das áreas marinhas deve ser vista como um instrumento flexível que deve considerar também o comportamento dos operadores. Devido à pandemia Covid19 observamos apenas 23 do total de 46 embarcações autorizadas. Os resultados mostram que medidas adicionais de conservação podem ser necessárias para o funcionamento sustentável da observação de golfinhos no estuário do Sado durante períodos sem pandemia.

PALAVRAS-CHAVE: Observação de golfinhos, padrão espacial, Kernel Density

ABSTRACT

This project work maps and analyses GPS data of touristic dolphin watching boats while they were in active observation of bottlenose dolphins (*Tursiops truncates*) in the Sado estuary and the adjacent ocean. The small group of 27 dolphins in the Sado estuary is one of very few groups in Europe, which do not travel but have a permanent habitat. The data set includes 292 data points which were collected within an observation effort of 130 hours in total on 22 different days during the summer of 2020. The results of an exploratory data analysis show, that dolphin watching was concentrated in the ocean along the peninsula of Tróia in summer 2020. The number of registered localizations per day went up to 33. High numbers of localizations mainly, but not always, coincide with high boat densities, which were quantified via a kernel density estimation. Marine touristic operators with a dolphin watching license were mainly localized in water depths till 20 m. The travel distance to their home port lies mainly in between five and 11 km. We registered no systematic infraction of the dolphin watching guidelines. Kernel density estimation proved to be a useful tool to map the extension and intensity of dolphin watching operations. The results may help to improve the information basis for the definition of an appropriate carrying capacity of the estuary's dolphin population. We conclude that the carrying capacity of marine areas should be seen as a flexible instrument which also should consider the operators behaviour. Due to the Covid19 pandemic we only observed 23, of the total of 46 authorized boats. The results show that further conservation measures might be necessary for the sustainable operation of dolphin watching in the Sado estuary during times with no pandemic.

KEYWORDS: Dolphin Watching, Spatial Pattern, Kernel Density

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I. Introduction

I. 1. Context – Dolphin Watching Tourism

Dolphin watching tourism can be labelled under the more global term of cetacean based tourism. Cetacean based tourism (CBT) is a globally growing sector in tourism and thus an important economic factor for coastal communities (Christiansen et al., 2010). It includes marine tours with vessels to watch whales and dolphins. The tours are organized by private business owners (Filby et al., 2015). CBT is often falsely labelled or misunderstood as a sustainable form of tourism. This would include an educational aspect of the tours. Furthermore, sustainable CBT tries to minimize possible negative ecological impacts of its operations (Burgin & Hardiman, 2015). Sustainable CBT can foster pro-environmental behaviour and can play an important role in sustainable economic development (Hassan & Syed Azhar, 2017).

Negative effects of CBT on the targeted population of whales or dolphins were observed in the past. Cetaceans showed evasive behaviour or left to another place when they were approached by a touristic vessel (Burgin & Hardiman, 2015). It is assumed that this may also lead to negative long-term effects on the population such as a lower reproduction rate (New et al., 2015; Pérez-Jorge et al., 2017).

In order to avoid such negative effects of CBT, good management practices are needed. These must control the human disturbance of the cetacean population (Duprey et al., 2008). Scientific research can help to identify harmful CBT practices and monitor the compliance of regulations (Rocha et al., 2020; Wiener, 2013).

I. 2. Study Area – The Sado Estuary and Adjacent Ocean

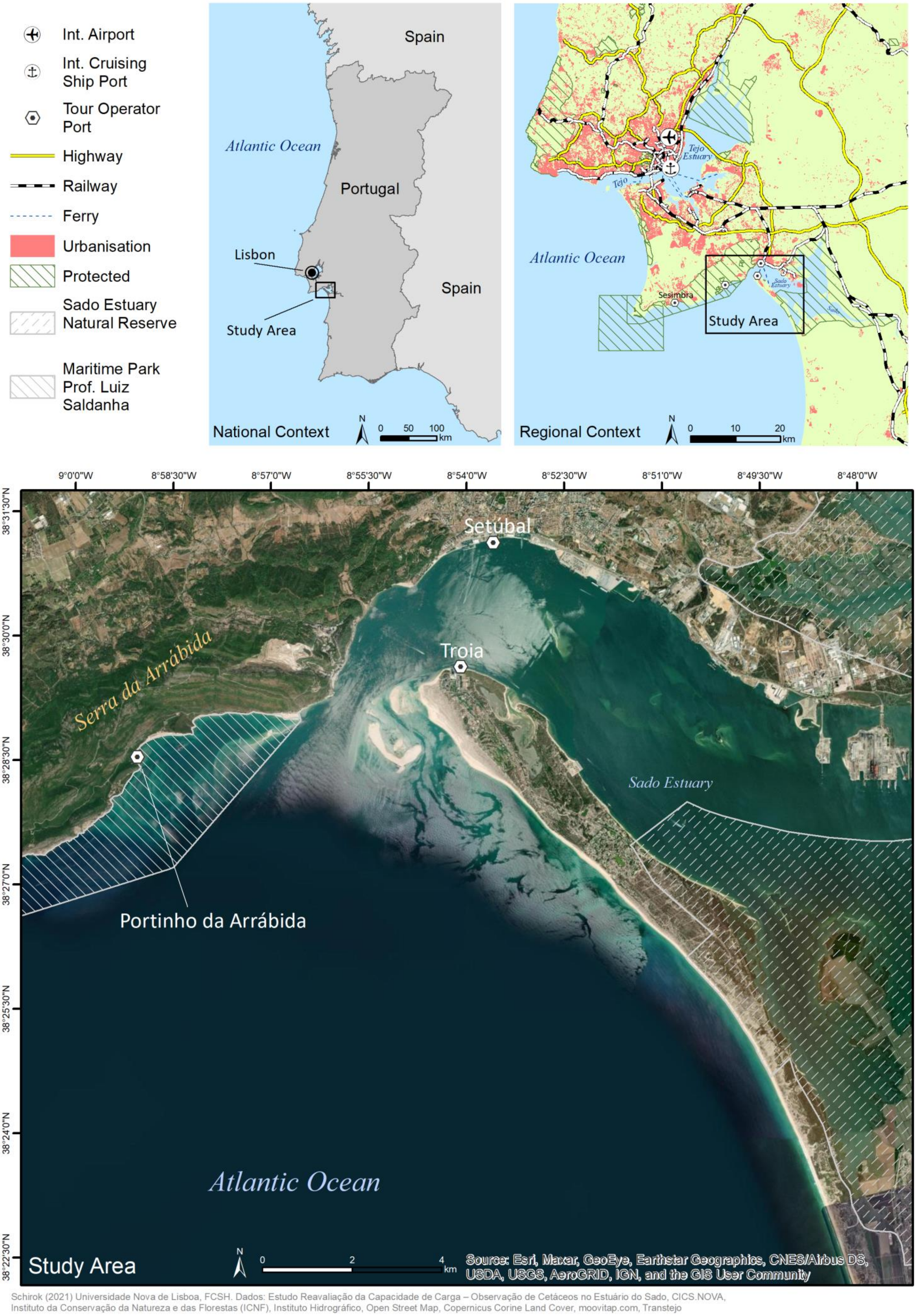
The Sado estuary is located on the west continental coast of Portugal, approximately 45 km southwest of the centre of Portugal's capital Lisbon. The Sado estuary encompasses together with the bay of Setúbal a water surface area of approximately 16.250 hectares (ha). The Sado river flows into the estuary, beside other smaller streams. The estuary is delimited by the peninsula of Tróia in the west. On the northern end of the peninsula the Sado estuary opens towards bay of Setúbal which opens towards the ocean in an approximately 2,3 km wide channel (Andrade et al., 2014;

Instituto Hidrográfico, w.d.). The Sado estuary is Portugal's second biggest estuary, after the Tejo estuary (Caeiro et al., 2005) (Map 1).

The shores of the eastern part of the estuary are characterised by wet meadows and marshland, with tidal flats (Neves, 1985). The western part, which includes the study area, is comprised of a northern channel which is of low depth and includes sand banks and a southern channel which is of more profound waters (Caeiro et al., 2005; Coelho, 2016). While the southern channel reaches a depth of 25m, the northern channel has a depth of around 10-15m. The northern channel is dredged in order to maintain it navigable for the commercial ships which use it to enter the industrial port of Setúbal. The reason for the different depths of the two channels is a stronger water flow in the southern part which allows less sediments to set (Andrade et al., 2014). Also, the underwater relief of the adjacent ocean area which forms part of the study area, is formed by the water stream of the Sado estuary. Just southwest of the northern end of the peninsula of Tróia is a spit which is comprised of a wide beach and sandbanks which reach around 2,6 km into the ocean (Instituto Hidrográfico, w.d.).

The eastern part of the estuary is a protected area. The *Reserva Natural do Estuário do Sado* was created in 1980 and has an extension of 23.160 ha (Resolução Do Conselho de Ministros n.º 182/2008, 2008). Since then, the reserve was object to several changes in regulation[1]. In 2006 the observation of cetaceans was regulated (Decreto-Lei n.º 9/2006 de 6 de Janeiro, 2006). The reserve area is an important habitat for birds and other species. The zone counts with 261 registered vertebrates (ICNF, n.d.-c). The nutrient rich tidal flats and waters are favourable for the biological diversity and prosperity (Bruxelas et al., 1992). For this work the local group of bottlenose dolphins (*Tursiops Truncatus*) is of specific interest. It is the only resident group of dolphins in Portugal and one of very few in Europe. The species normally travels along the coastlines and oceans (ICNF, n.d.-c).

[1] For the regulation history of the *Reserva Natural do Estuário do Sado* see http://www2.icnf.pt/portal/ap/r-nat/rnes/legis [20.08.2021]



Map 1: Study Area within national and regional context

Parts of the adjacent ocean of the study area belongs to the *Parque Marinho Prof. Luiz Saldanha* which is part of the *Parque Natural da Arrábida*. The marine protected area stretches along the southern coast of the Setúbal peninsula, from *Cabo Espichel* in the west till the *Serra da Arrábida* in the west. It was created in 1998 and counts with an area of 5.200 ha (Decreto Regulamentar n.º 23/98 de 14 de Outubro, 1998) [2]. The coastline is mostly rocky and has cliffs, which is unusual as the rest of the coastline is sandy till the Tejo river towards the north and Sines towards the south. The mountain ridge of the *Serra da Arrábida* protects the coastline from the dominant north winds and ocean waves from the northwest. Thus, the water is relatively quite in comparison to the rest of the rough Portuguese coastline. This may be the reason for the development of species which are not to be found in the rest of the Portuguese waters. Animals use the area to recreate and reproduce (ICNF, n.d.-b).

The biggest city on the shore of the estuary is Setúbal with approximately 120.000 inhabitants (Instituto Nacional de Estatística, 2013). Setúbal is home to an important industrial port, from where automobiles are exported which are produced on the Setúbal peninsula (jornaleconomico.sapo.pt, 2020). The center of Lisbon is around 45 km away. Setúbal and Lisbon area connected by train and highway. A car drive from the Lisbon center to Setúbal takes around 45 minutes, from Lisbon airport around 35 minutes. Lisbon attracted high and before the Covid19 pandemic rising numbers of tourists (INE, 2021). Lisbon has an international airport and cruising ship port. Another tourism magnet is the *Serra da Arrábida* with its Natural Reserve and the town of Sesimbra. Another center of attraction for tourists and visitors is the Tróia peninsula. Along the estuarian side of the peninsula are several marinas as there are at the foot of the *Serra da Arrábida*. Also, Lisbon and the nearby Cascais have significant marinas. This leads to a high number of visitors in the study area. It is to assume that the number of visitors to the region will rise in the future. There are plans for a second airport for Lisbon and development projects for apartments and hotels on the Tróia peninsula and in the *Serra da Arrábida* (expresso.pt, 2020; jn.pt, 2021; publico.pt, 2021).

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[2] For the regulation history of the *Parque Natura da Arrábida* see http://www2.icnf.pt/portal/ap/p-nat/pnar/legis [20.08.2021]

I. 3. Research Problem - Regulation of Dolphin Watching in the Sado Estuary

A small group of 27 bottlenose dolphins inhabits the estuary and the ocean nearby currently on a permanent basis. Among them are four calves and three adolescents (ICNF, 2020). They regularly move in between open waters and the estuary (Grilo, 2010; Vilhena, 2010). The population size decreased from 40 individuals in 1986 to around 30 animals around the year 2000. In 2007 there were only 26 animals in the group (Vieira da Silva, 2008; Gaspar, 2003).

The *Tursiops Truncatus* dolphins are on the red list of threatened species. They hold the classification "least concern" (IUCN, 2018). They are protected by international, national and local legislation (ICNF, 2020). The group of dolphins in the Sado estuary is specifically endangered because of the relatively old age structure of the group. Also, the relatively small size of the group hinders a healthy development of the population. Gaspar formulated that an extinction of the group in the long term is probable, considering the low number of individuals in the group (2003). Thus, conservation measures are necessary in order support the survival of this group of bottlenose dolphins in the region (Coelho, 2016; Vieira da Silva, 2008).

Besides water pollution and fishery, harassment by touristic dolphin watching activities counts as one of many factors threatening the well-being of dolphin communities (Bejder et al., 2006). Bernardo (2012) has observed the interaction of the local dolphins in the Sado estuary with different types of vessels. She registered a negative response of the dolphins, in particular with marine touristic operator vessels and privately operated boats. Other types of vessels, such as passenger or cargo ships seemed to be less invasive, even though they crossed the dolphin's territories. Thus, there has been efforts to establish a carrying capacity for touristic dolphin watching activities in the Sado estuary and adjacent ocean area (Andrade et al., 2014).

The concept of a carrying capacity assumes that every system has a maximum number of users, who can use a system without compromising its main services:

> *"The CC [carrying capacity] […] should be considered as the limit from which the resource is saturated (physical carrying capacity), environmental characteristics are degraded (ecological carrying capacity) and user's enjoyment decreases (social carrying capacity)."*
> *(Pereira da Silva, Fonseca and Nogueira Mendes, 2020, p. 920)*

This means for our case, that the group of dolphins in the Sado estuary can be watched by a certain number of touristic vessels, without endangering its viability. The goal is, not to overuse the ecological resource "dolphin population" for touristic means in order to preserve the ecological and economic benefits for the future.

In 2011 there were 4 companies registered with 8 boats for the activity of dolphin watching in the region. The numbers raised to 22 companies and 46 boats registered and authorized in 2020 (Pereira da Silva, 2020). The number of boats operating inside the estuary was limited to 17 (Edital de 5 de Abril 2019, ICNF). The high amount of touristic boats might be a major threat for the sustainable development of the bottlenose dolphin's population in the Sado estuary (Andrade et al., 2014; Mustika, 2011). Moreover, the threatening of the group means a threatening of the local dolphin watching companies and touristic industry in general. This makes monitoring and management of the touristic dolphin watching activities necessary. The authorization of the 46 registered boats happened without a previous study of the carrying capacity of the dolphin population which might lead to an endangerment of the population by the number of authorized boats.

The carrying capacity is defined by the maximum number of persons which can use a determined area. It is also applied to the observation of cetaceans. The maximum number of users should be determined by the *Instituto da Conservação da Natureza e das Florestas* (INCF) on a yearly basis (Decreto-Lei n.º 9/2006 de 6 de Janeiro, 2006). The definition of the carrying capacity should be based on available scientific information. Yet, science can still not provide an exact rule for the definition of the carrying capacity for dolphin watching. In order to improve the implementation of an adequate carrying capacity, the existing pressure of touristic dolphin watching should be registered and associated impacts should be studied (Andrade et al., 2014).

In order to get a better understanding of the impact of the touristic dolphin watching boats we study the spatio-temporal distribution and density of their occurrence. The spatial and temporal distribution of the touristic boats are important factors for the determination of their ecological impact (Hammitt & Cole, 2015). Where and when do they observe the dolphins and how many of them are doing observation at the same time? Another important aspect to study is the compliance of the existing dolphin watching guidelines. Observation standards have no effect, if they are not followed (Cecchetti et al., 2019). Hence, another research question of this work is about the compliance of local tour operators with the regulation.

II. Methodology

II. 1. Data Collection

The raw data for the data set we use in this project work was registered in summer 2020 within the research project *Estudo Reavaliação da capacidade de carga – observação de cetáceos no estuário do Sado* (Revaluation of the carrying capacity – Observation of cetaceans in the Sado estuary) funded by Tróia Natura (Pereira da Silva, Fonseca e Nugueira Mendes, 2020a) (Figure 1). The data set we use was obtained during an observation time of 130 hours and has registrations on 22 days in the period from 23th of July till 10th of October 2020. Hence, 29% of the days within the research period were covered with field observations.

Figure 1: Part of the team of CICS.NOVA (Ricardo Estevens, Ricardo Nogueira Mendes, Beatriz Nobre) during field observations (Photography: Pereira da Silva, Fonseca e Nogueira Mendes, 2020a).

The research project has a collaborative setup. The operators were included in the research process via several workshops. Preliminary results were presented and discussed. We could collect valuable qualitative data in conversations with the operators during those workshops which were recorded in field notes.

The summer of 2020 was very untypical due to the global Covid19 pandemic. Further data collection campaigns are planned for the future in order to get a more realistic picture. The operators reported lower numbers of visitors which coincides with the low number of international tourists visiting Portugal in 2020. Yet, operators also reported higher numbers of privately operated boats. Even though we could register a considerable amount of valid data, the series of field trips was also designed to test and evaluate the observation methodology. Because of the pandemic, the results should be seen as approximations and cannot be taken as a representation of the situation in a normal year. Still, we can validate the used methodology with the results.

Geodata collection was traditionally conducted via questionnaires for wildlife tourism research. For marine surface use with boats, logbooks were used typically. Since it is available for the broad public and scientific research, the use of Global Positioning System (GPS) data turned out to be more accurate (Hallo et al., 2012; Palomo & Hernández-Flores, 2020).

The GPS system is based on at least 24 satellites orbiting the earth. Twice a day the GPS satellites orbit the earth in a precise circle. They continuously transmit a signal to earth. GPS receivers use a coordinate system to locate themselves. The receiving GPS unit compares the time a signal was transmitted by a satellite, with the time it needs to receive the signal. In sum it is the time the signal needs to cover the distance from its origin, the satellite, to the receiver, the GPS user. Knowing the distance, the signal covers in a certain time frame, the GPS-receiver knows that he has a certain distance from the satellite. But it yet does not know if its position is in that distance towards north or east for instance. When these measurements are available from at least three different satellites, the PS receiver can calculate its exact position. The satellite signals can pass through transparent objects like glass and can also overcome atmospheric distortions. But they cannot pass through physical objects like buildings, mountains or vegetation (El-Rabbany, 2006; Hallo et al., 2012). As our data was collected on an open water surface, it should be reliable.

The most accurate way of collecting GPS data of boat positions, is to put the GPS tracker directly on the boats (Palomo & Hernández-Flores, 2020). This was not possible in our case for several reasons. First, from a total of 46 registered boats we did not know before hands which would leave the port on the considered day. It was also not possible to contact all boat owners and ask them for cooperation. As the boat owners use different ports it was also not possible to wait for them and hand out the GPS trackers while they leave for dolphin observation. Furthermore, it should be stated that even though many boat owners have a generally positive attitude towards our project, some may have a more critical stance or might feel controlled excessively, carrying a GPS tracker on their boat, which should be respected in order to maintain a collaborative working atmosphere.

Thus, the GPS points for the touristic boats in active dolphin observation were set on the basis from GPS data from another boat accompanying the boats. This other boat belongs to the ICNF and sets out regularly to monitor and organise the touristic dolphin watching activities. The research team members were on the ICNF boat and were regularly carrying a GPS tracker to register their own position. When a situation of active dolphin watching was observed, the researcher registered the time and measured the distance between the boat of the ICNF where he or she was on, and the azimuth towards the touristic vessel (Figure 2). The time was registered in order to be able to later identify his or her own position from the GPS trackers records. The azimuth is the angle from an imaginary line from point A towards north and the direction of another point B (Richner, 2015). In our case, point A is the ICNF boat where the researcher is positioned and point B is the touristic boat which is in active dolphin observation (Figure 3). With the GPS data of the ICNF boat, the azimuth and the distance between the two objects the position of the touristic boat can be calculated (Richner, 2015).

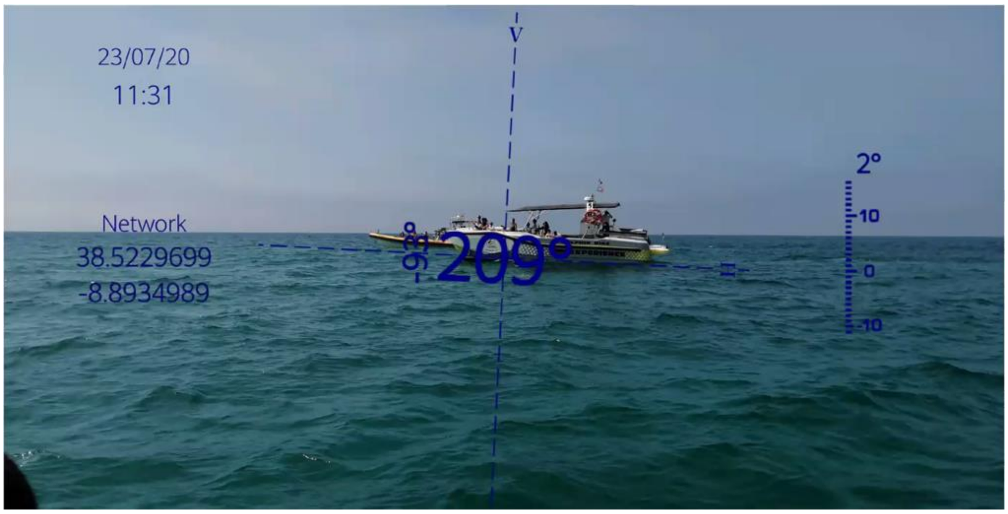


Figure 2: Observation of touristic dolphin observation boats: registration of the azimuth (Photography: Pereira da Silva, Fonseca e Nogueira Mendes, 2020a)

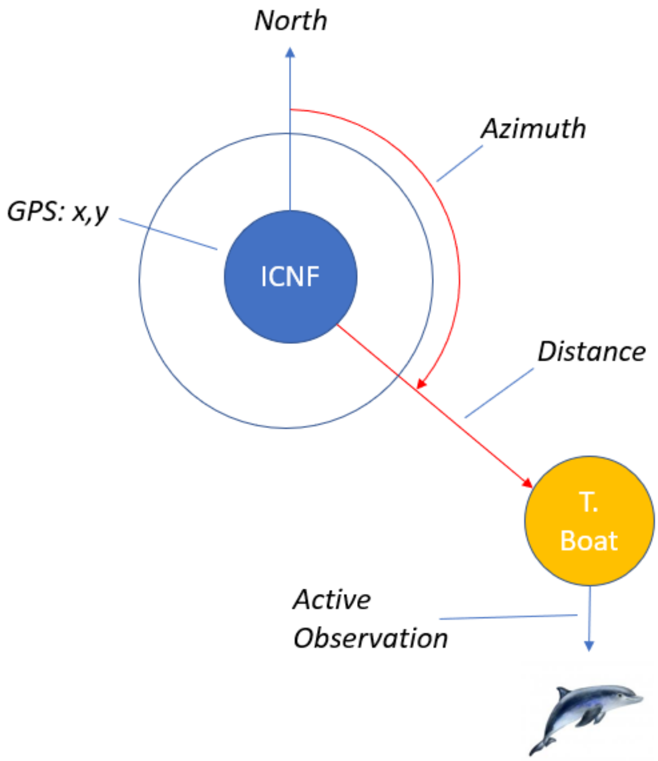


Figure 3: Model of the technique to calculate the geographic position of the touristic boat in active dolphin watching (own elaboration on basis of Richner, 2015)

II. 2. Data Processing

The data which was registered on observation sheets was digitalized. The next step is the organisation of the data in a database. There are several ways of organizing data in a database. Modern geodata is mostly organized within a relational database. In a relational database the information is saved in multiple files which can be connected, if necessary, via an identification key. The advantage is that every single file is smaller in size and easier to keep updated then if all the data would be stored in one single file (Campbell & Shin, n.d.; Lange, 2013). Our dataset does not have the extend that would make it necessary to apply a relational database and we stick to a flat database model. The flat database model is easier to set up and gives a better overview over the data. It consists of what we basically see in a normal excel sheet. A combination of rows and columns which relate to each other in a certain cell (Campbell & Shin, n.d.).

As a next step we transformed the information from the database into a file type which can be used within a geographic information system (GIS) software (Lange, 2013).

We used ArcMap 10.7.1 from the company Esri as GIS software. A common file type of geodata is a shapefile. This type of data can also be used in open-source GIS software, such as QGis. We also worked with the newer file type Geodatabase. It mostly works with less errors and has faster performance capacities (Childs, 2009; Happ, 2015).

II. 3. Data Analysis

The software ArcMap was also used for the analysis of the data. The software offers a Python interface and with ArcPy a Python package which allowed us to conduct the spatial analysis functions of ArcGIS in Python. We used Python and ArcPy when the prefabricated options of ArcMap were not sufficient for our data analysis goals. To write the Python code we used the programme PythonWin 2.7.16.

In order to gain knowledge from the obtained data and information we used several spatial analysis techniques. Spatial analysis tries to identify spatial patterns in spatial data (Flitter et al., 2014). To achieve that, several approaches are possible.

Flitter et al. identify three main components of spatial analysis within geographic information systems. First, there is the explorative and qualitative approach. This approach is purely visual and means to explore the data with the eye. In this phase hypothesis about possible patterns can be formulated. The formulated hypothesis can be tested later with other techniques (Flitter et al., 2014). The eye has a stunning capacity to analyse large quantities of data in a very short period of time when they are well prepared (Tenedório, 2020). When we look at geographic data, we mostly instantly see some patterns which call for further analysis.

As one of two “hard” analysis technique Flitter et al. present the geometric spatial analysis. It focuses on the location and attributes of the objects. It is mainly descriptive and cannot be used for hypothesis testing. Examples for geometric spatial analysis include network analysis, nearest neighbour, point distribution, analysis of distance relations or the calculation of point density (Flitter et al., 2014).

Another quantitative method is of geostatistical nature. Within this class of analysis techniques, it is possible to test hypothesis statistically, which were elaborated beforehand via the visual analysis of the data for instance. A classic case would be to test for spatial correlations: How does the location of the points from a certain class influence the location of points from another class (Flitter et al., 2014)?

II. 4. Exploratory Analysis

We started with the qualitative technique and solely looked at our data in the GIS software. We could see, that our point data seemed to have a pattern, which calls for spatial autocorrelation and cluster analysis in order to identify, if the pattern are statistically significant (Cliff & Ord, 1973) (Map 2: Data Set, p. 20). Yet, due to the relatively small amount of point data, the cluster analysis results did not seem meaningful. The identified patterns lead us however to other techniques, with which we can better identify and visualize the point data pattern. We are especially interested in point density, as a high point density also stands for a higher local level of disturbance for the dolphins, and thus chose the kernel density technique for further elaboration (Silverman, 1998).

Another aspect of further investigation which emerged from the qualitative analysis, is the identification of the bathymetric data of the boat positions. We could see, that the boats did not seem to enter the open ocean on a regular basis and were wondering, if this could be documented in the bathymetric data as well.

Beside the qualitative analysis of the geographic data, we structurally reviewed our fieldnotes from the field trips in order to identify possible themes for further investigation or explanations for the quantitative data. The boat operators mentioned, that the distance towards the port plays an important role in the planning of their trips, as they have a time limit for the tours they offer and also have restrictions regarding the expenditure for diesel. Both affects the maximum distance they can travel from their home ports. Accordingly, we were wondering if we could identify patterns in the distance towards the home ports of the operators.

II. 5. Spatial Autocorrelation

Spatial autocorrelation indicates the strength, with which variables influence each other, depending on their distance to one another. A positive spatial autocorrelation means, that a certain value in a geographical location, the appearance of a certain number of touristic dolphin watching boat for instance, goes hand in hand with a similar value, the appearance of a similar number of touristic dolphin watching boats in our case, in a neighbouring geographic measuring unit. This coincides with Tobler's law of Geography: "*Everything is related to everything else, but near things are more related than distant things."* (Tobler, 1970, p. 237) Negative spatial autocorrelation means the opposite: Similar values are dispersed in space (Li et al., 2012).

We would like to draw the attention towards the case of no spatial autocorrelation, which is the same as a random distribution of values in space. Our eyes capacity to intuitively recognise pattern in data, might trick us in this case. Random distributions may be intuitively misunderstood as spatially autocorrelated data (Figure 4). Thus, it is important to run a statistical test for autocorrelation.

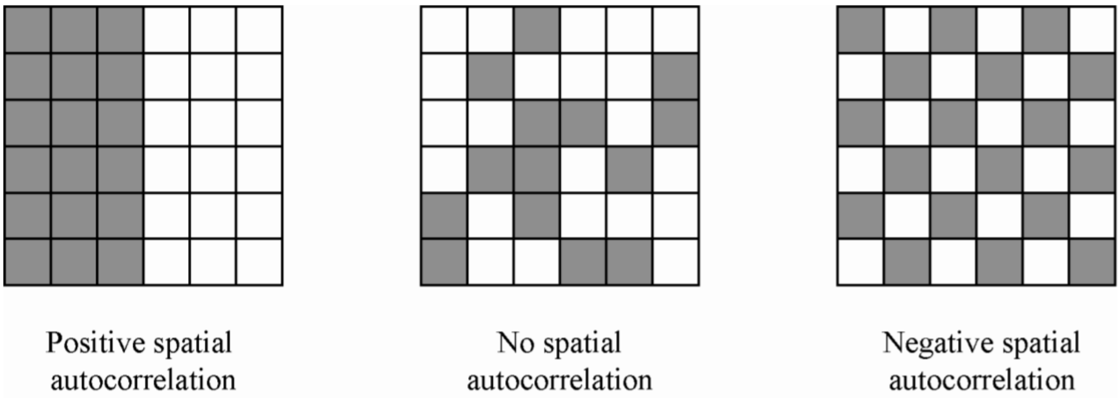


Figure 4: Examples of positive, no and negative spatial autocorrelation (Radil, 2011, p. 44).

There are several statistical tests which can identify spatial autocorrelation. Even though - because of the lack of a bigger data sample - we will not go deep into statistical analysis of our data, it makes sense to test for spatial autocorrelation in order to know if our data has a statistically significant pattern or is randomly distributed in space. If our data would be randomly distributed, we could still describe it, but we could not find reasons for the distribution or hope that the described distribution follows some general rules and is thus valid also for the future (and past): *"Spatial randomness is where you go home and you can't do anything."* (Anselin, 2017)

II. 6. Location Parameter

To get a general idea of our dataset we used two spatial statistics tools: Mean centre and directional distribution. The mean centre identifies the geographical centre from a set of geographical data, points in our case (**Fehler! Verweisquelle konnte nicht g**

efunden werden.). It is given as the mean of the coordinates of the point data. It can be useful for the comparison of data from different time periods or the comparison of different types of data (Mitchell, 2020). In the figure below, the classical example of cholera cases in 19th century London is shown (Snow, 1855). Snow mapped the cholera cases and figured out that they were spread around one contaminated water pump. Would he have had GIS at his hand, he also could have identified the contaminated pump using the mean centre (**Fehler! Verweisquelle konnte nicht gefunden werden.**). W e used the mean centre to see the centre of the activity of the touristic boats but also to compare the geographical difference between different types of boats.

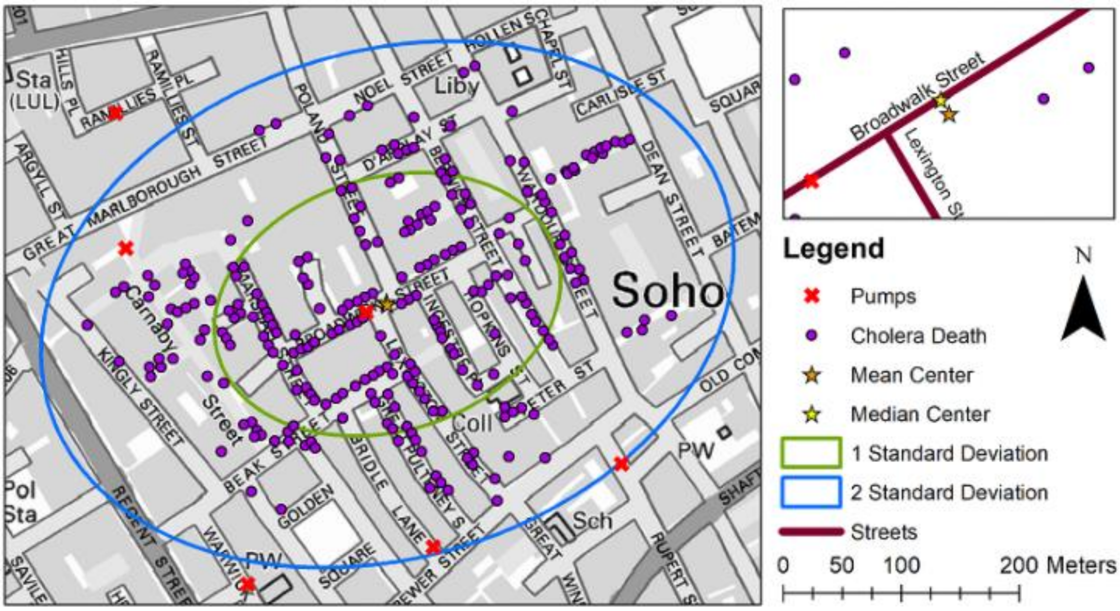


Figure 5: Map of cholera cases in London. The mean centre indicates the contaminated water pump. The median centre is another centre parameter. The directional distribution ellipse indicates the directional trend and spread of the cases. It can be wider or narrower, depending if the standard deviation is multiplied (Data: Snow, 1855; Map: Yuan et al., 2020).

The directional distribution indicates the directional trend of the data. It is represented by an ellipse. The axis of the ellipse is calculated with the standard deviation of the x- and y- coordinates from the mean centre. The ellipse tells if the data is elongated towards one direction (Figure 5). Comparing different data sets with the directional distribution, we can identify on the one hand, if a data set is more spread or concentrated as the other, and on the other hand if the data sets have different directional trends (Mardia & Jupp, 2000). We used the directional distribution in order to compare the spread and distributional trend of the different type of touristic boats.

II. 7. Kernel Density

Density maps show concentrations of point data. They present a continuous surface in order to illustrate the location, value and density of the input data points. They also allow us to quantify the concentration and thus compare densities in different areas (Yuan et al., 2020). The figure below shows again the example of cholera cases in London. Even though we have different areas with point agglomerations, the density map shows that the concentration of cholera cases is highest close to the pump next to the mean centre of the cases (Figure 6). For our data, the density map shows us where and when we have high concentrations of touristic boats. We can also compare the densities of the different types of boats. It allows us to identify and study the spatio-temporal distribution of the touristic boat activities.

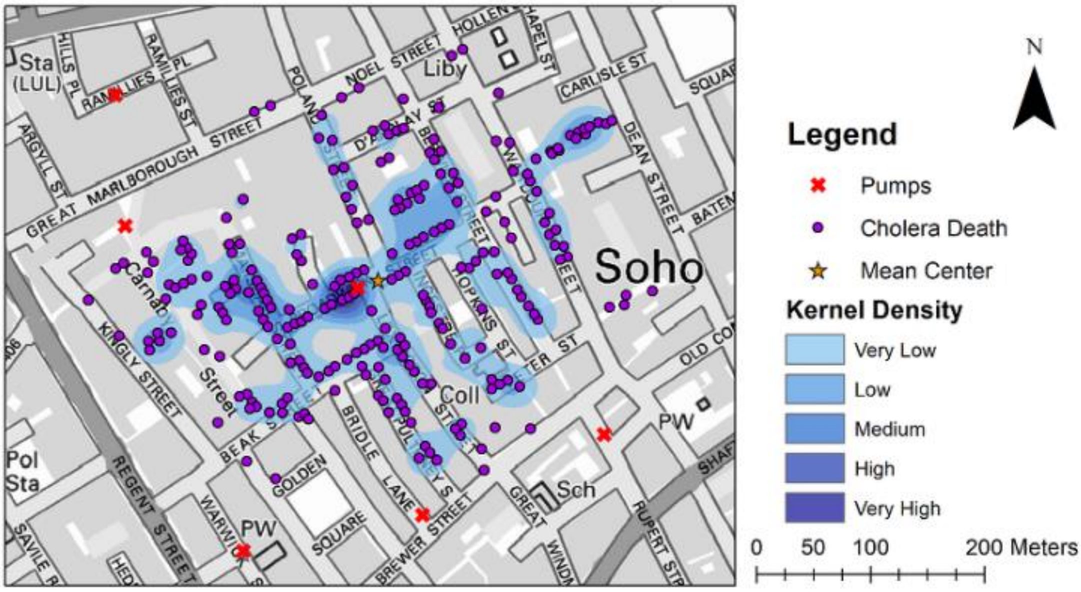


Figure 6: Kernel density map of cholera cases in London (Data: Snow, 1855; Map: Yuan et al., 2020).

Kernel density fits a smoothly curved surface over each point. The value of the surface is highest at the location of the point and diminishes with increasing distance. It reaches zero at the search radius distance from the point, which is mostly called bandwidth. To calculate the kernel density for various points, the values of the different points are added up at each location or raster cell[3] (Silverman, 1998) (Figure 7).

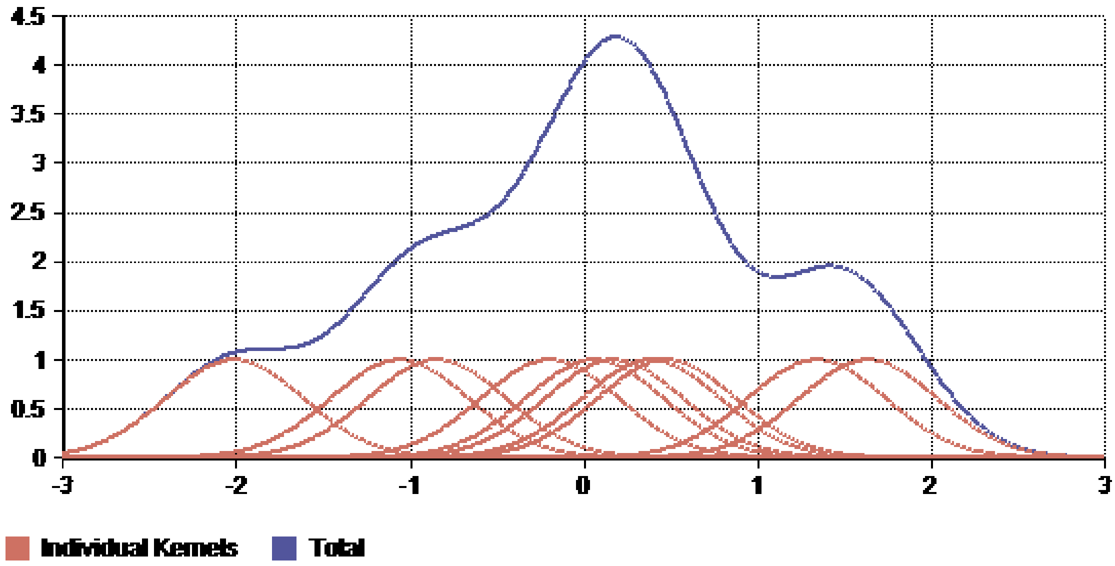


Figure 7: Individual kernel densities (red) and the summed up total kernel density (blue). Each individual kernel density represents a data point. The location of the data point (bottom axis) is where the red curve is highest. Data points could also have different values, then the lines would be higher or lower. In this case all data points have the same value (left axis). Changing the bandwidth, would change the width and height of the red lines. The differential of the lines represents the point value and will not change by changing the bandwidth (adapted from Analytica, n.d.).

A point of many discussions is the bandwidth selection (Heidenreich et al., 2013). With a low bandwidth, the overall spread of the kernel density surface is low but the peaks are higher where there is a high concentration of data points or values. With a high bandwidth, the overall spread of the mapped surface is wider. Even though there are several rules of thumb, we can choose a bandwidth specifically for our type of data if we have an argument at hand. Yuan et al. chose a relatively low bandwidth in order to illustrate the concentration of cholera. If we imagine a bandwidth of 200m for example, almost the whole map would be blue, which would not meet the goal of indicating the hot spots (Figure 6). But are there any objective arguments for a reasonable bandwidth for cholera cases?

For the observation of dolphins by touristic boats, we answer this question on the basis of the code of conduct for dolphin observation. The code of conducts sets the approaching zone for dolphin observation at 300m (ICNF, n.d.-a). That means that from

[3] For further explanation on raster cells see (Campbell & Shin, n.d., p. 75).

this distance on, boats have to obey the dolphin watching guidelines. We thus concluded that on the one hand 300m are considered a critical distance for the well being of the dolphin population, considering approaching observation boats, and on the other hand, it is an important benchmark for the boat operators. Accordingly, we decided to use a bandwidth of 300m for the kernel density estimation.

II. 8. Boat-Dolphin Distances

In order to investigate the compliance of the dolphin watching guidelines, we measured the distance between the observing boat and the dolphins. From a methodological perspective, the measurement of the distance between two points can be considered as a classical geometrical tool in the toolbox of spatial analysis instruments (Flitter et al., 2014).

The data for the measurement was registered in the field, while the boats were in active observation. That means, that the boat ended its journey in search of the dolphins and was either inside the 300m approaching zone in order to watch the dolphins or waiting outside that zone till it was its turn to enter. Our main goal was the registration of the localization data of the touristic boats. When the situation allowed it, we also registered the localization data of the dolphins under observation. Due to the dynamic situation in the field, this was not always possible. We also want to point out again, that this data set is based on the first series of field trips and is thus also considered as a test series in order to improve the methodology. We found the registration of the localization data for boats *and* dolphins especially challenging, as the boats and also the dolphins are moving objects. We also could not register their position simultaneously, thus the data are to be considered as approximations.

III. Results

III. 1. Data Set

The data set we work with has 292 boat localizations in total. Among them are 228 positions of marine touristic operators with dolphin watching license (MTO). The other datapoints are made up of 16 datapoints for tour operators who offer touristic tours but do not have a license for dolphin watching and 48 datapoints for privately operated boats. The MTOs were registered by name. Thus, we know that we have registered 23 individual MTOs during our observation (Map 2).

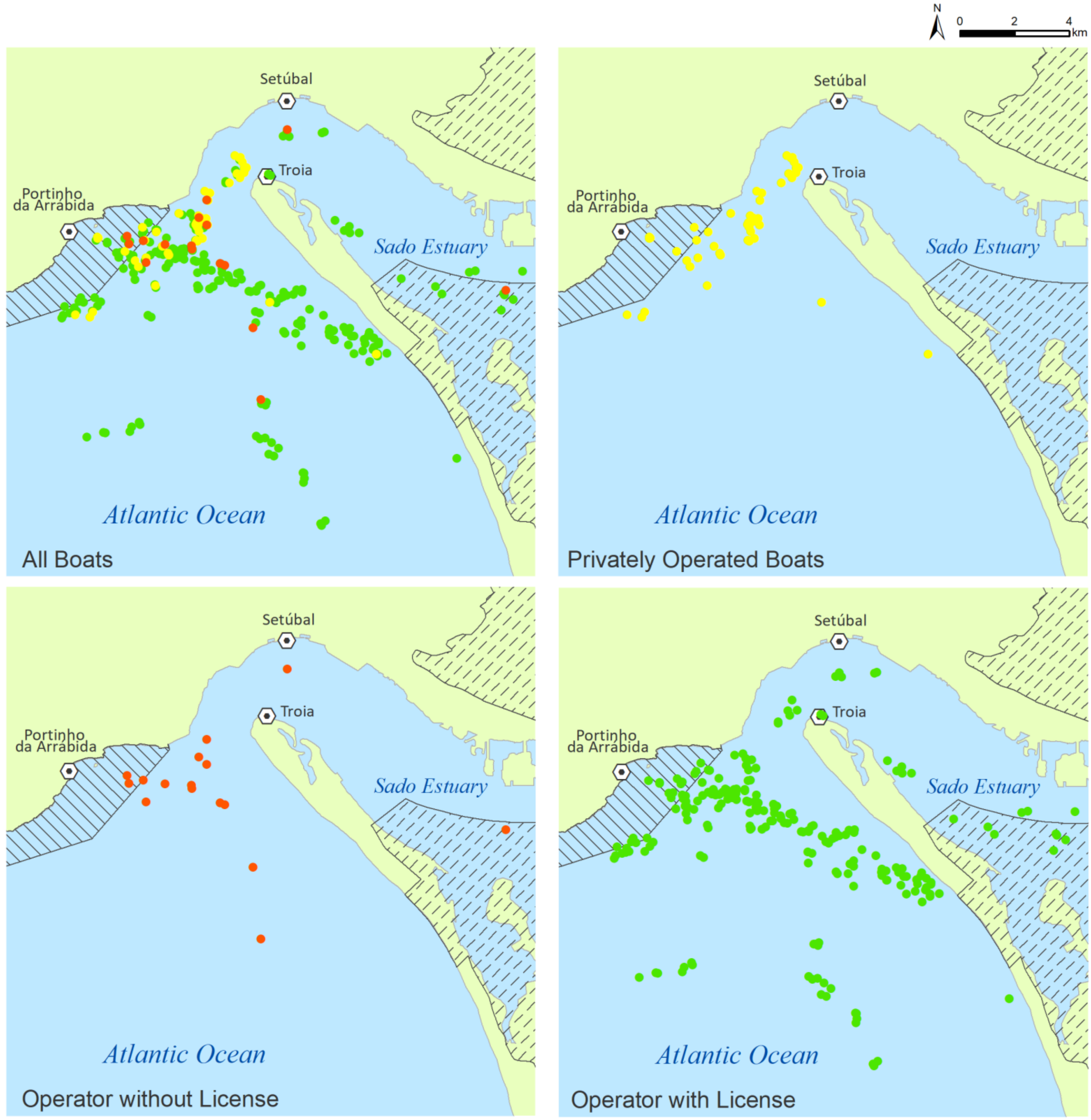
By barely looking at the map, where boat localizations are represented as points, we can already identify interesting aspects which shall be studied more with further analysis techniques. Following points seem interesting to us:

- The positioning of all boats does not seem to be random but follow a pattern.
- The boats show different agglomeration densities.
- The different boat types privately operated boat, tour operator without and with license seem to have different operation areas.
- Even though the majority of activity is outside the protected areas, there are some boats localized within the protected areas.

Following Anselin (2017) and considering our first bullet point above, we test for spatial autocorrelation of our data first. The spatial autocorrelation tool of ArcMap uses Moran's I statistic, which is a commonly used test statistic to identify spatial autocorrelation (Anselin, 2019; Mitchell, 2020; Moran, 1948).

Our data points are binary. Either there is a boat (1) or not (0). As we did not register when there was *not* a boat, all our values are 1. Yet, the spatial autocorrelation tool needs a variety of values in order to calculate the test statistic. Therefore, we create a fishnet with 500 m x 500 m cells and then register how much events fall into each cell. We select the cells with values and get 110 cells with values from 1 to 13. We then calculate the spatial autocorrelation with the cell values.

Localization of Touristic Boats During Dolphin Observation	
Operator with Dolphin Watching License	228
Operator without Dolphin Watching License	16
Privately Operated Boat	48
Total	292
Number of Boats of Tour Operators with License	23
Number of Registration Days	22
Observation Time	130 hours
Time Period	23.07.2020 - 10.10.2020



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Map 2: Data Set of the data collection campaign of dolphin watching boats in the Sado estuary in summer 2020 with point data of different boat classes

The result shows that the data is spatially autocorrelated. As we can see in the figure, that means that the localizations of the boats are clustered (Figure 8). The boats concentrate in certain areas. The autocorrelation value for the data is quite high. The z-score of 5,39 lies far above the highest critical value of 2,58 and the indicated p-value is zero. We have to take into account, that some of the autocorrelation is based on the geography of our study area but has no relation to our research questions. As we study boats, we already know that they will be found only in the water. Yet, the fact that not all of the study area is comprised of water makes up for some of the spatial autocorrelation. In the following we will describe in more detail the boat areas and investigate possible reasons for the clustering.

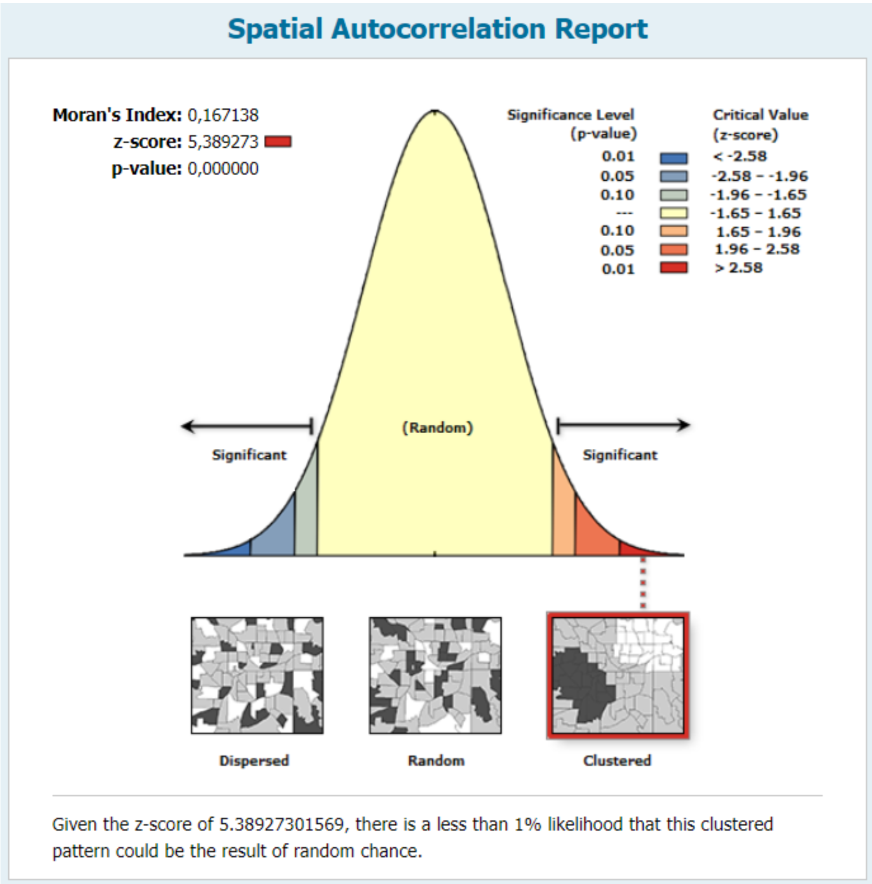


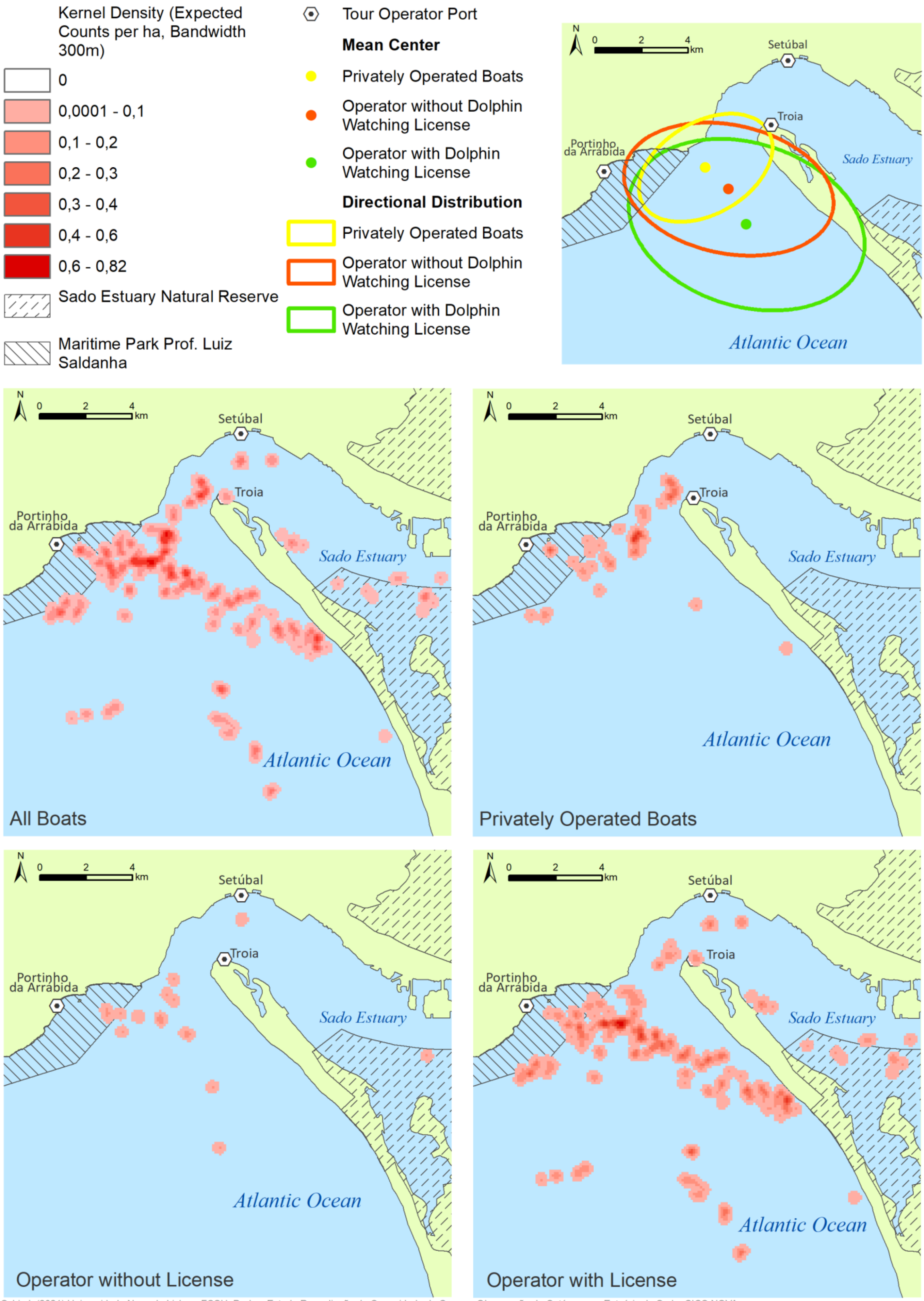
Figure 8: Spatial Autocorrelation Report output from ArcMap for dolphin watching boat localizations. The result indicated a significant spatial autocorrelation (own elaboration with ArcMap).

III. 2. Geographic Distribution and Density of Boats

The location parameter mean centre indicates the geographical centre of boat activity. The centre of activity of all boat classes is located around 2 km southwest of the shore of the peninsula of Tróia. The privately operated boats stay closer to the bay of Setúbal than the professional tour operators. The tour operators with license for dolphin watching (MTO) move away most from the bay. They mentioned in conversations that many privately operated boats come from inside the bay or estuary and are hesitant to move far away from their home ports and further into the open ocean. According to the MTOs, most privately operated boats also do not actively search the dolphins but follow them when they see them by chance or they come when they see a gathering of MTOs. The same counts for the operators without dolphin watching license. This could be another reason why the privately operated boats and operators without license are not to be found as much in the open waters as the MTOs. The MTOs themselves are experienced in the search of the dolphins and know that they sometimes are to be found southwards and thus follow this direction (Map 3).

The directional distribution shows that the privately operated boats are to be found mostly along the north-western shore of the mainland, where we also find less wind and ocean swell (see Study Area). The locations of the MTOs stretch along the peninsula of Tróia. The operators without license fit geographically in between the other two boat classes.

The four kernel density maps demonstrate the geographical distribution, density and area of influence of the dolphin watching boats. The output values show the predicted number of boat localizations within each 100 x 100 m cell. *Prediction* does not stand for the designation of a value for another point in time in this case, but for the designation of a value at another geographical location. As the kernel density does unfold the value *one* which is located at one point over a surface, it predicts the values which are thus spread over space.



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Map 3: Location Parameter and Kernel Density for different classes of dolphin watching boats

The geographical distribution of the kernel density of the privately operated boats follows mainly the pattern we have already discovered through the location parameters. The operators without license show a widespread geographical distribution. It ranges from deep inside the estuary till the open ocean, but does not show such a big concentration in comparison with the other boat types. The MTOs are mainly distributed along their directional distribution axis but have outliers in the whole study area. The density of the privately operated boat localizations shows a concentration on their mean centre, in between Tróia and Portinho da Arrábida, but also just west of Tróia. The density of the tour operators without license does again not show a concentration in one area. The MTOs have a high density of activity along their directional distribution axis, with higher densities towards the two ends of the axis. The sizes of the areas of influence coincides with the number of registered localizations of each boat class. Calculating with a 300m radius around each localization, the operators without license cover 396 ha, the privately operated boats 726 ha and the MTOs 2.801 ha.

The kernel density map shows, that the boats have activity and even considerable concentrations inside the protected areas. From the total of 3.009 ha covered by the boats, 453 ha are protected areas, which makes up around 15 %. The highest kernel density value, looking at all types of boats together is 0,813 (Figure 9). It is located around 4 km east of Portinho da Arrábida. The mean kernel density value for all boats together is 0,097. Inside the protected areas, the highest values lies at 0,396. The agglomeration is located inside the Maritime Park Prof. Luiz Saldanha around 1 km east of Portinho da Arrábida. The MTOs may enter the protected areas legally if they have an appropriate registration. The observation of dolphins inside the protected areas from privately operated boats is more problematic. Yet, the Maritime Park Prof. Luiz Saldanha is not properly marked by buoys, as an operator lamented. Privately operated boats might just not notice when they enter the protected area.

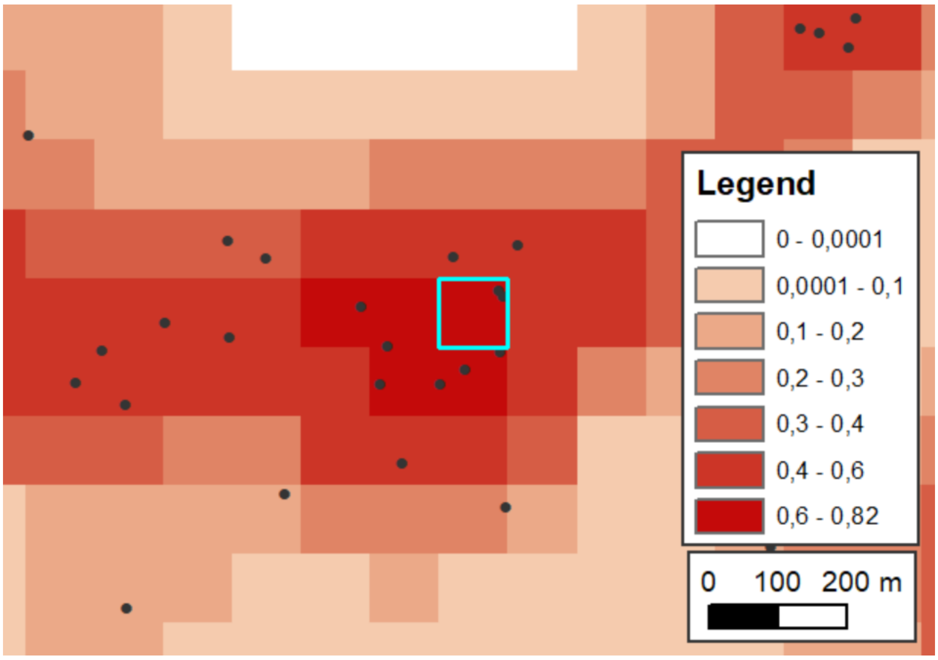
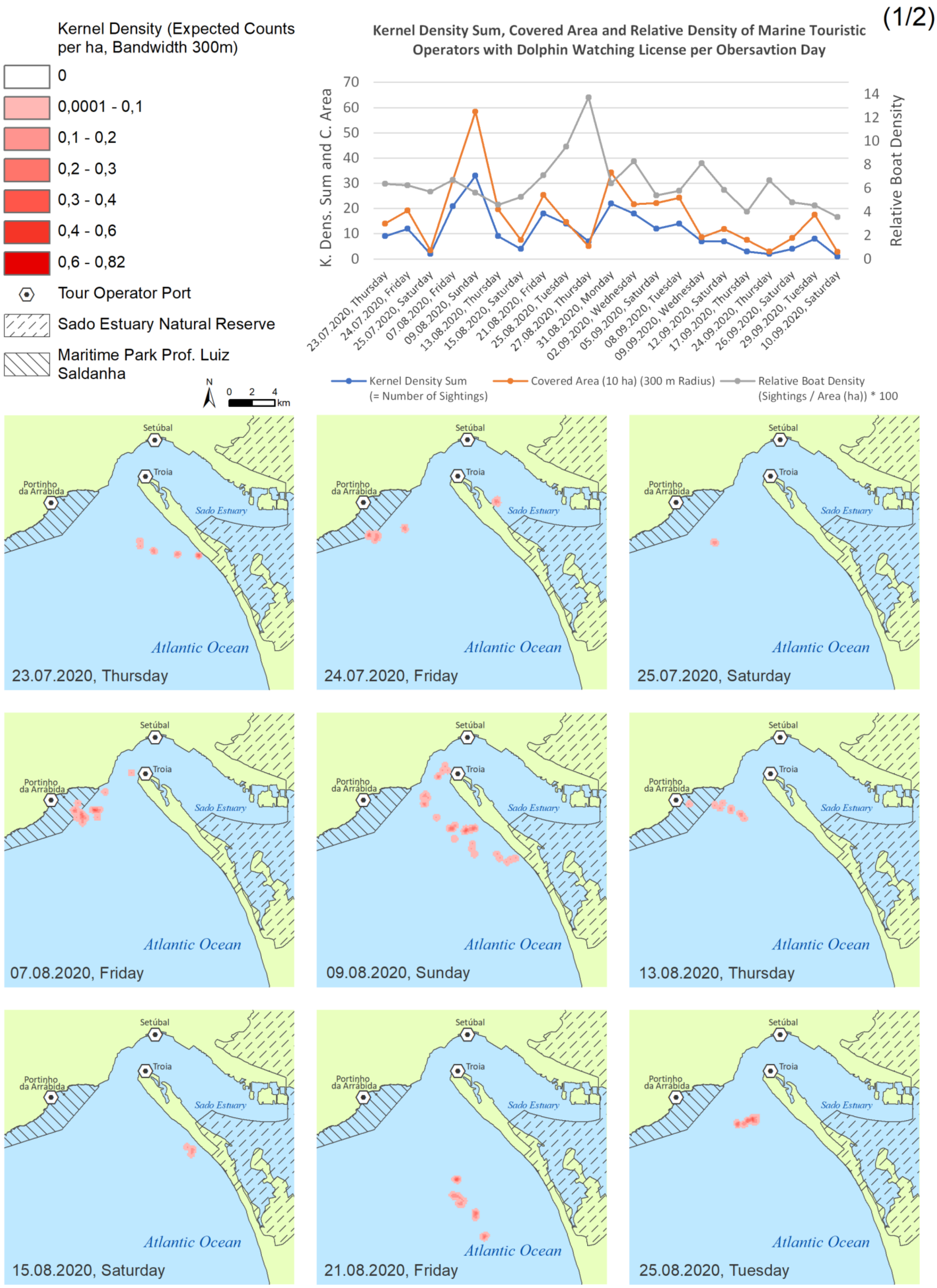


Figure 9: Exemplary presentation of the kernel density value expected counts per cell (legend) for different dolphin watching boat densities with a bandwidth of 300 m. The black points are dolphin watching boat localizations. The marked 100 m x 100 m cell indicates the highest registered kernel density value of 0,813 (own elaboration with ArcMap).

We point out that the kernel densities and location parameters presented in this chapter are based on the whole dataset which covers 22 different registration days. In the next chapter we present the kernel densities of the data differentiated by the day of registration in order to have a more accurate estimation of the spatio-temporal pressure the boats have on the dolphin population.

III. 3. Spatio-Temporal Analysis of Boat Density

The next map shows the geographical distribution, density and area of influence of marine touristic operators with dolphin watching license (MTO) per observation day. The graph indicates the number of sightings and covered area by the MTO on each day. It also shows the relative boat density. We focus on the MTO for two reasons: First, they make up for the bulk part of our data. Second, they are the focus of the research project the data was collected for in order to inform possible changes in regulation of MTOs (Map 4 and 5).



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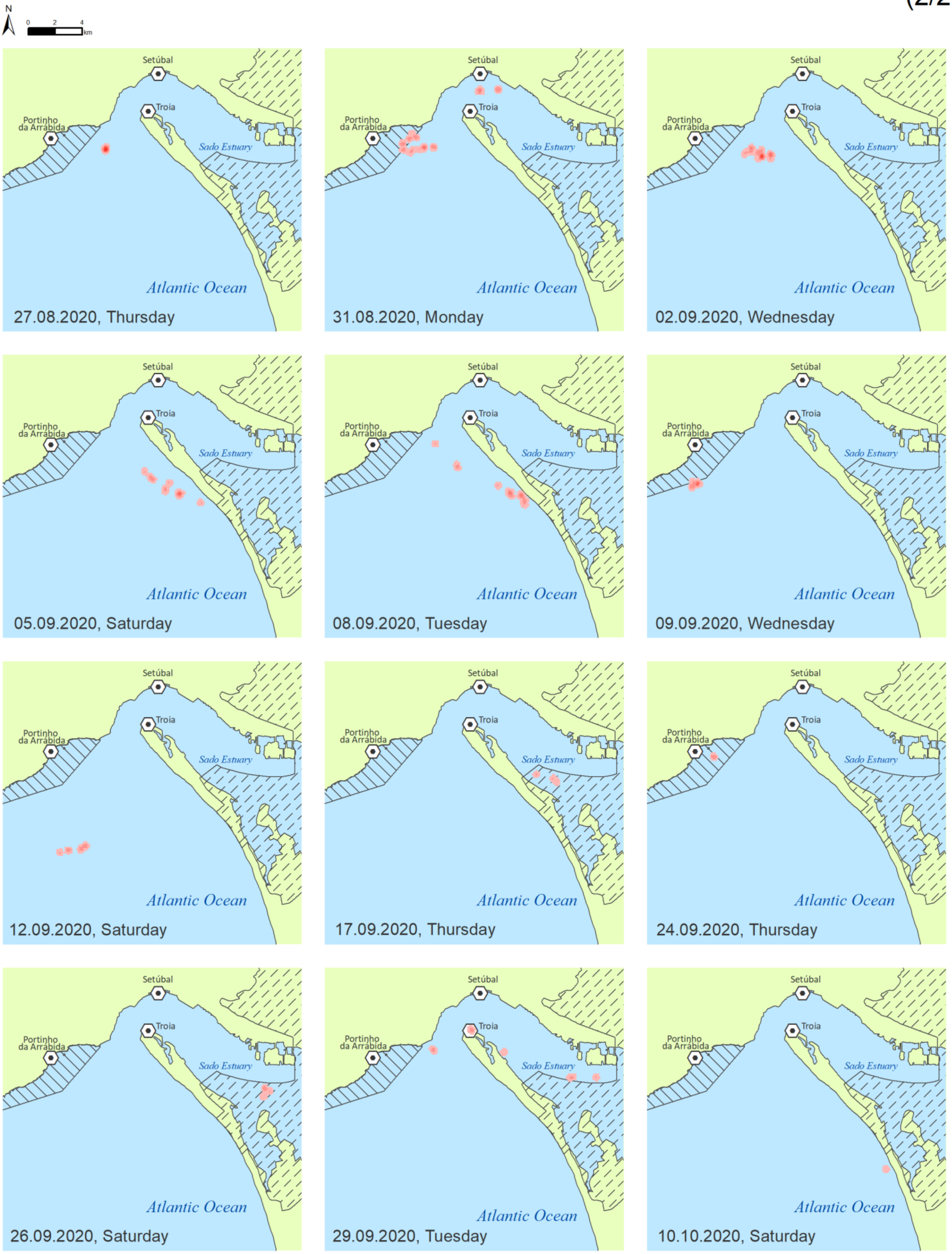
Map 4: Kernel Density per day, covered area in ha and boat density of marine touristic operators with dolphin watching license (Page 1)



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Map 5: Kernel Density per day, covered area in ha and boat density of marine touristic operators with dolphin watching license (Page 2)

The mapping of the kernel density per day works as a spatio-temporal model for the pressure applied on the dolphins by the MTOs. The maps show when and where the disturbance occurs and with which relative level of intensity. All localizations were registered during the day. We have no knowledge of touristic boat activities during the night. We also point out that the data was collected during summer because it is the most important season for the operators considering the number of clients and tours.

The mapping of the registered data points is geographically accurate (still there is some error term from the registration of data, as described in the methods chapter). In relation to time, we note that even though two appearances of MTOs happened at the same day at the same location, they might have happened at different times of the day. Thus, a geographical overlap does not necessarily stand for an overlap timewise.

On most days (14) we registered operations of the MTOs only outside the estuary. On two days the operators were exclusively inside the estuary. The operators reported, that in other years the dolphins are to be found more often inside the estuary. On some days the activities were well spread over the study area (24.07., 09.08., 31.08., 29.09.), but in most cases, they concentrated in one region. This can be explained by the nature of the activity of the operators: they search the dolphins and after they have found them in one area, they have provided their service and then they head back to port. The spread of activities on one day can be explained with the different time periods the data was collected during the days. Usually the operators offered two tours, one in the morning and one in the afternoon. It happened that the dolphins were to be found at one spot in the morning and at another in the afternoon. On the 10.10. we see that the operators had to travel far in order to find the dolphins. If it was not because of a low number of active boats on that day, the general low activity of dolphin watching on that day might be related to the high travel distance necessary to find the dolphins. We will address the travel distances of MTOs in more detail in the next chapter.

On 9 of the 22 observation days the MTOs were either watching dolphins inside a protected area or their 300m radius was reaching inside. We also want to point out at the situation on the 09.08. just west of Tróia. The dolphins regularly travel between the inside and outside of the estuary or bay area and the ocean. They have to pass the narrow channel west of Tróia. This is a sensible zone as also many MTOs and other boats use the channel in order to depart or get back to the ports inside the bay and estuary area. The situation on the 09.08. depicts a possibly critical moment when boats and dolphins encounter in the narrow channel. The freedom of movement of the dolphins, especially the travel direction in or out of the bay might be blocked by the boats.

We also registered on which day of the week the data was collected. The hypothesis is, that there is more activity on the weekends. Counting Saturday and Sunday as weekend, we cannot confirm the hypothesis with the data. We registered on seven weekend days 63 localizations, which makes an average of 9 localizations per day. On 14 days during the week, we registered 164 localizations, which makes an average of 11,71 localizations per day.

The graph indicates the sum of the kernel density values per day, which equals the total number of sightings of that day. The lowest value is one on the 10.10., the highest numbers of localizations of MTOs was registered on the 09.08. with 33 localizations. The median value is nine. Furthermore, the graph indicates the area covered by the boats, calculating with a 300 m radius around the boats. The biggest area was covered on the day with the highest amount of registered boat localizations (09.08.) with 584 ha. The lowest value for the covered area coincides with the day with the lowest number of boat localizations (10.10.) with a covered area of 28 ha.

The grey line indicates the relative boat density. It is calculated as the ratio of the number of boats and the total covered area. The highest boat density was registered on the 27.08., where seven boats covered an area of 51 ha. The lowest value was registered the day we only registered one boat localization (10.10.). The relative boat density index shows that a high number of boats does not necessarily coincide with a high boat density. Thus, considering possible spatial pressure on the dolphin territory, we have to take into account the total amount of covered area by the boats on the one hand and the boat density on the other hand.

III. 4. Characteristics of Operation Area

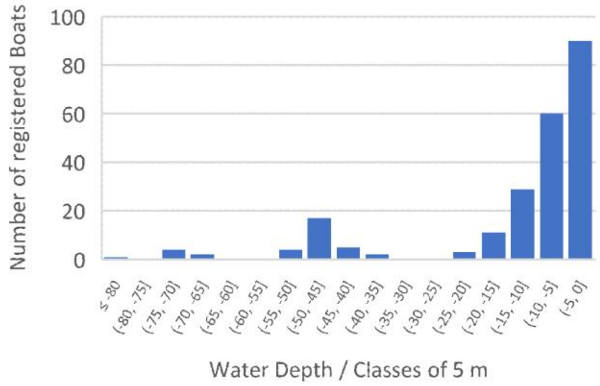
In this chapter we present the bathymetric data of the marine touristic operators (MTOs) localizations. In the following we demonstrate data which indicate travel distances of the MTOs to their home ports. The description of the operation area with these data shall help us to identify and describe the localization pattern of the MTOs in more detail. It is also a starting point for the analysis of the reasons and driving forces for the identified geographical pattern (Map 6).

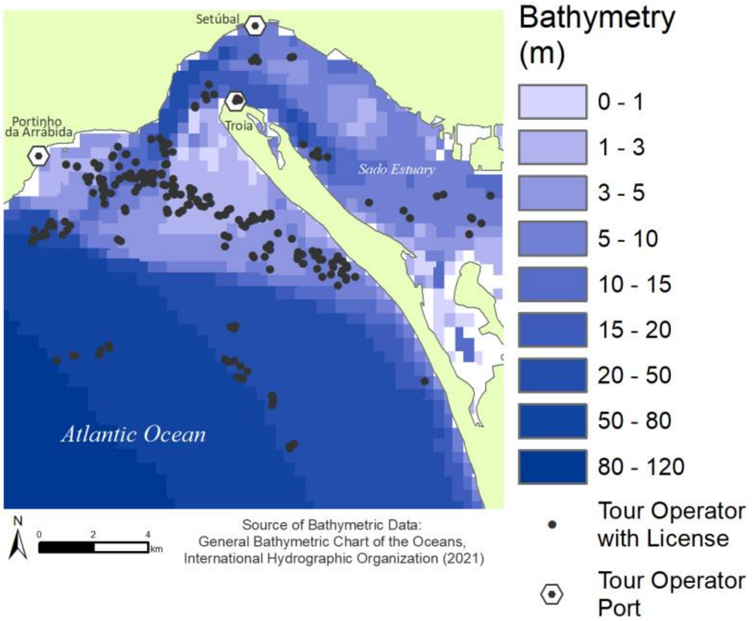
The bathymetrical relief of the study area has 4 different characteristics. The estuary includes the shallow northern channel where we also find sandbanks, and the southern channel with depths of up to 25 m (see Study Area). The southern channel leads into a relatively deep channel of around 15 m which is carved out by the main water flow out of the Sado estuary and leads into the open ocean. At both sides of this channel, we find relatively shallow zones. At the north-western side, close to Portinho da Arrábida, many areas are only a few meters deep or have sandbanks. On the south-eastern side of the channel is a sand spit which reaches out around 2,6 km from the peninsula of Tróia into the ocean (see also Study Area). The sand spit is mainly not navigable and covers and area of around 422 ha. Lastly, the study area includes open ocean with depths of up to 120 m.

We see MTO localizations in all four areas. But the activities are concentrated in the channel from the estuary towards the ocean and the adjacent shallow areas. This impression is confirmed by the median bathymetric value of 7 m. The mean value is with 13,1 m higher. This difference can be explained by the handful of localizations in the open ocean, which contribute a maximum bathymetry of 81 m and can be considered as outliers in the bathymetric panorama. The distribution of values in the graph shows a strong tendency towards the lower end of the scale. The number of localizations seem to rise significantly from a bathymetry of 20 to 15 m. The minimum value of 1 m supports the finding that the boats prefer the shallow areas and also approach the sandbars.

Bathymetric Data (m) of Boat Localizations of Operators with Dolphin Watching License

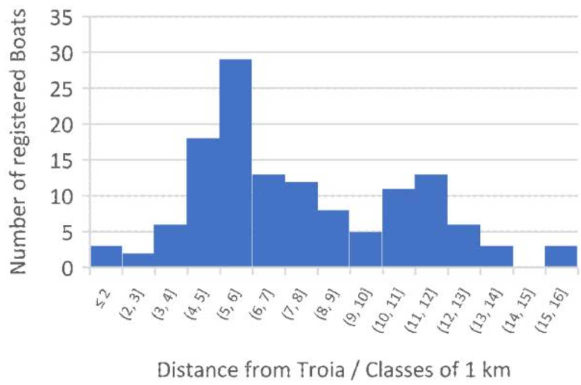
Count	Minimum	Maximum	Mean	Median	Stand. Deviation
228	1	81	13,1	7	17,26

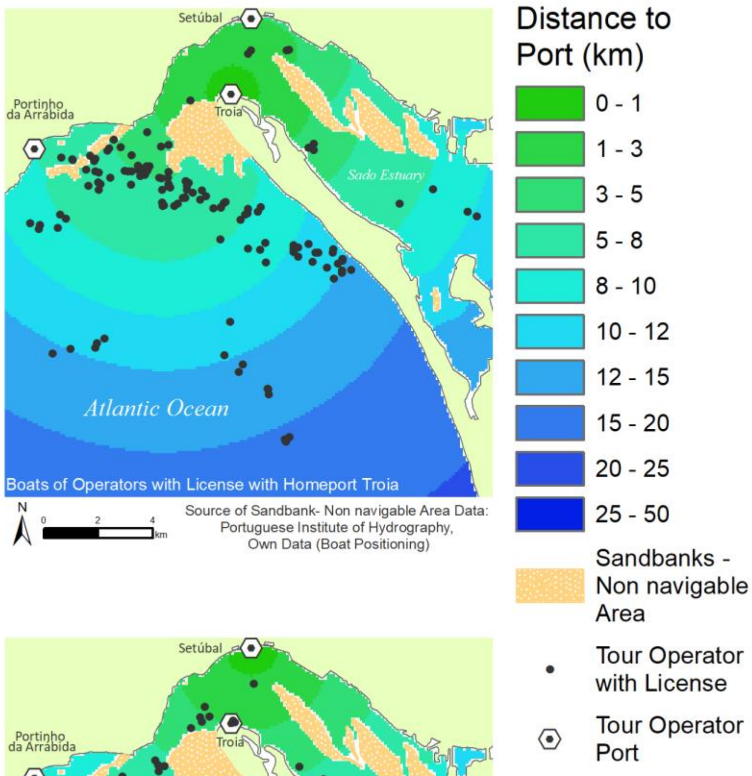




Distance to Troia (km) of Boat Localizations of Operators with Dolphin Watching License with Homeport Troia

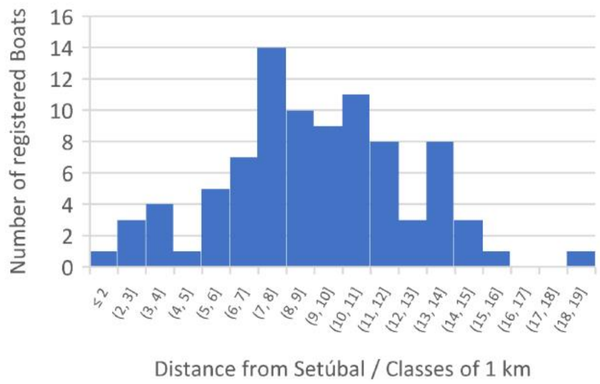
Count	Minimum	Maximum	Mean	Median	Stand. Deviation
132	1,519	15,565	7,558	6,348	3,126

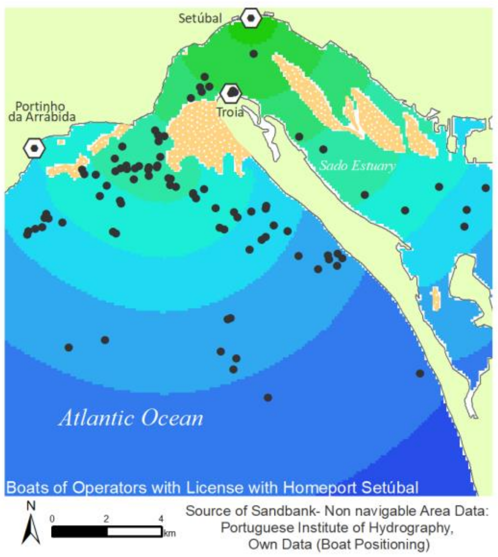




Distance to Setúbal (km) of Boat Localizations of Operators with Dolphin Watching License with Homeport Setúbal

Count	Minimum	Maximum	Mean	Median	Stand. Deviation
89	1,312	18,702	9,065	8,628	3,314





Registered Boats with other Homeports
Sesimbra 4
Portinho da Arrábida 2
Unknown 1

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Map 6: Bathymetry and distance to home port of marine touristic operators with dolphin watching license

The bathymetric relief does not directly attract the MTOs to enter certain areas. In contrast it prevents the boats to enter some areas, namely the shallow sand spit southwest of Tróia. The pattern suggests that they would enter this area if they could. Though, the relief is probably a reason for the dolphins to be around some areas more than in others, and the MTO follow where they can.

Beside the non-navigable areas, the distance to the home port is another restriction which hinders the MTO to follow the dolphins with more rigour. Two factors are responsible for the distance restriction: Time and Energy. On the one hand, the operators do not want to exceed their usual travel time of some hours in order to deliver on their promise to the customers of a half day tour, on the other hand they have to pay more for fuel the farer they travel and thus try to avoid far distances.

We calculated the travel distance of each localized MTO to their home port. We take into account the non-navigable areas, namely the sand spit close to Tróia and other sandbanks. Almost all boats are based either in Tróia (132) or Setúbal (89). As the dolphins were found mostly outside the estuary by the operators this year, the travel distances from Setúbal were longer in general. The maximum travel distance (18,702 km), mean (9,065 km) and median travel distance (8,628 km) from Setúbal to the dolphin watching site in comparison to the maximum travel distance (15,565 km), mean (7,558 km) and median travel distance (6,348 km) from Tróia indicate a generally shorter journey from Tróia. The lower median values in comparison to the mean values of both home ports show that there are long distance travel outliers in both home port data. For Setúbal, the first quartile lies at 7,118 km and the third at 11,102 km. For Tróia, the first quartile lies at 5,221 km and the third at 10,217 km. The quartiles indicate that 50 % of the localizations were registered in between the distances marked by them. The third quartile also marks the distance which 75 % of the boats did not surpass. We see that both distance distributions have most registrations in the mid-range of the values.

III. 5. Boat-Dolphin Distances

The last results chapter deals with the compliance of the code of conduct. The dolphin watching guidelines have clear and exact rules. It is not allowed to move in front or at the side of the dolphins. If a boat wants to approach the dolphins, it should come from the back angle. The approaching zone starts at 300 m around the dolphins. In the zone of 30 - 100 m around the dolphins, maximum three boats are allowed. At 30 m lies the minimum approaching distance, no boat should go closer to the dolphins (Figure 10).

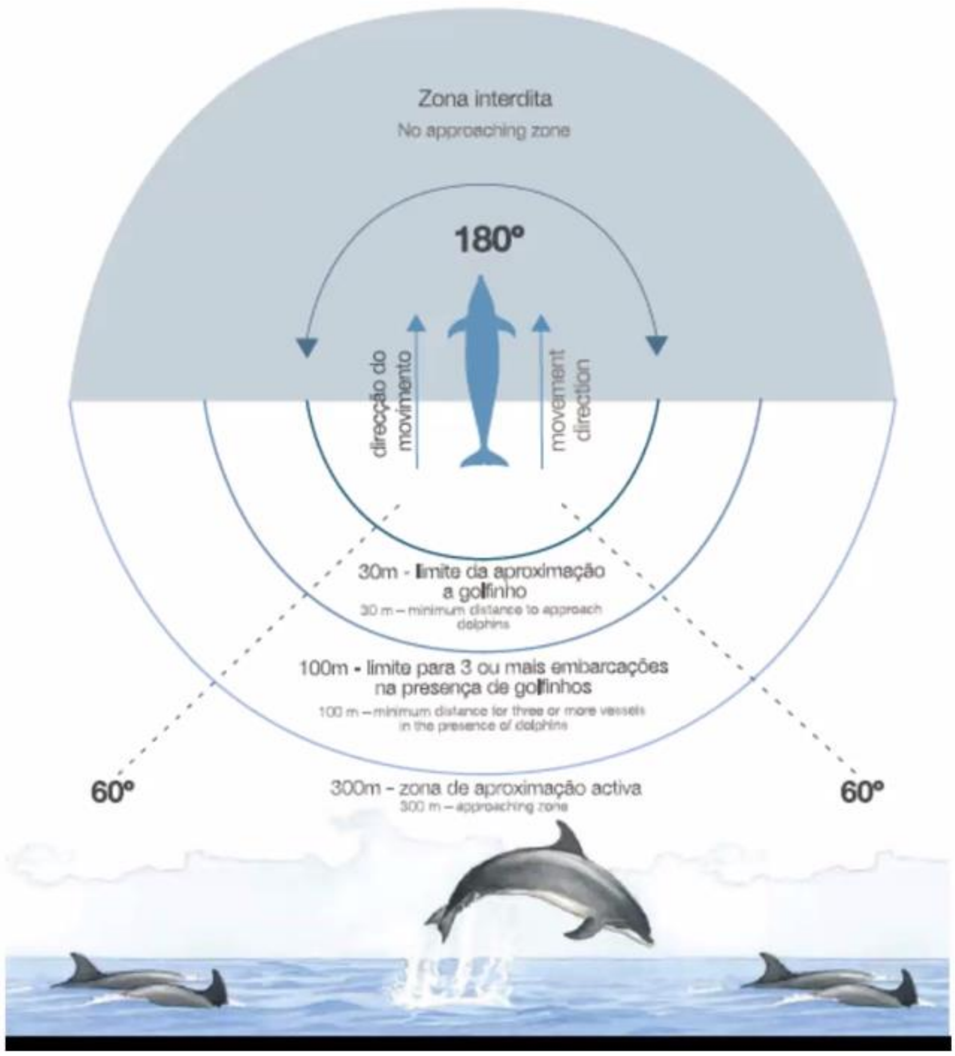


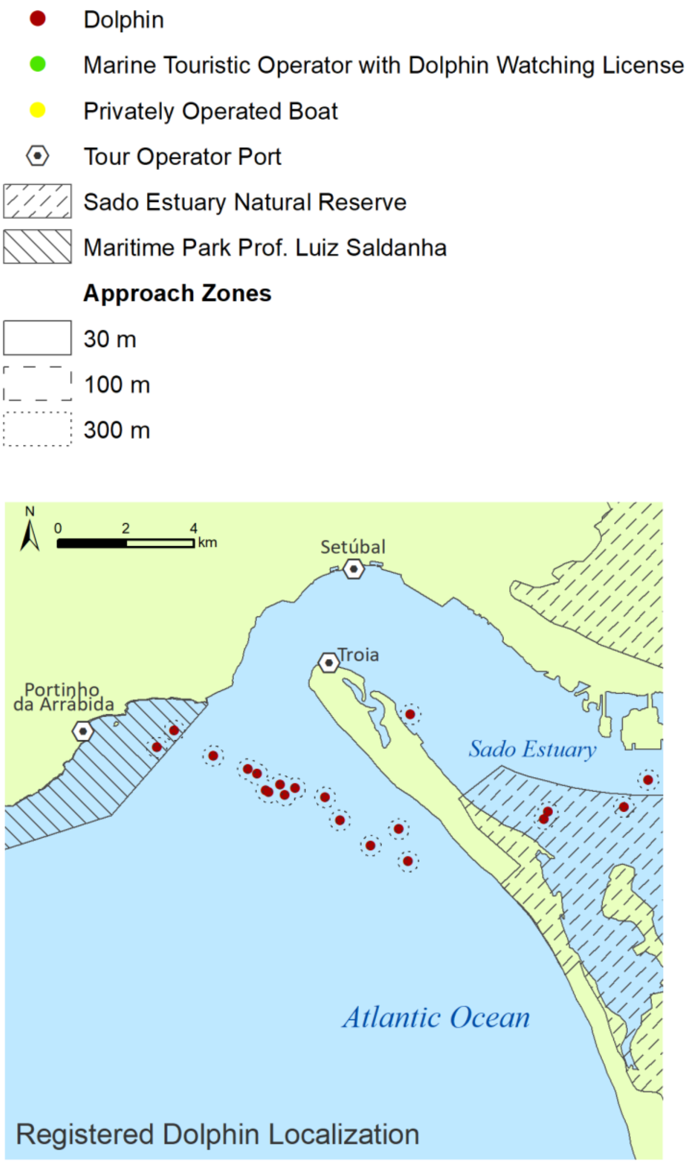
Figure 10: Code of conduct for the observation of dolphins in the Sado estuary (ICNF, n.d.)

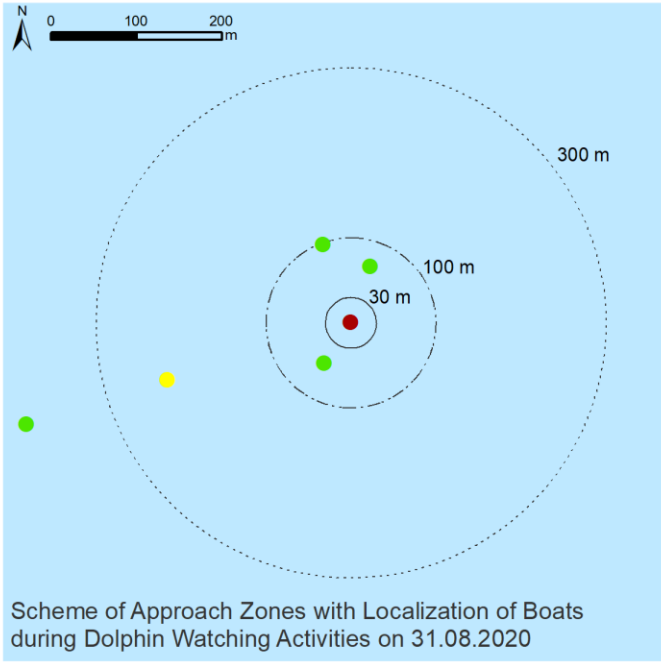
During the data collection we tried to localize the touristic boats and the dolphins. Though, our focus lied on the boats and due to the dynamic and sometimes complex situation with a lot of different research objects in the field, we could not always register the localization of the dolphins. Due to practical reasons, we also did not consider the approaching direction of the dolphin watching boats. Anyhow, we can tell from our research experience that the approach direction guidelines were followed in general.

We could register 20 localizations of dolphins while they were under touristic boat observation. The localizations follow mainly the pattern of the registered MTO data. There are localizations inside but mostly outside the estuary. Few localizations are within the protected areas. Most localizations stretch along the peninsula of Tróia (Map 7).

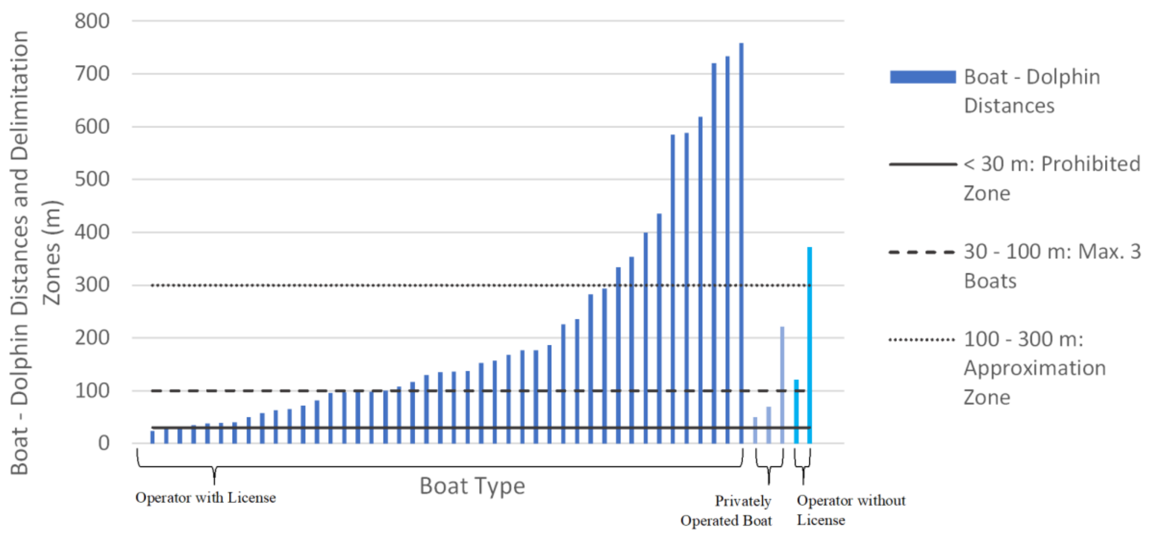
The map on the right side shows a scheme of how we analysed the distance between the boats and the dolphins. Considering the code of conduct, we were interested in the distance of the boats towards the dolphins and the number of boats which are close to the dolphins at the same time. The map shows an example of one observation situation where several boats were observing the dolphins simultaneously.

We measured the observation distance of 45 MTOs, three privately operated boats and two tour operators without license. There were three situations with boats within the 30 m zone. Anyhow, in two of these situations the measured distance lies just under 30 m and a measuring error might be responsible for the infraction of the allowed minimum distance. In the third case, the measured distance is zero. We observed in the field, that the dolphins sometimes are interested in and approach the touristic boats themselves. We thus conclude that we did not register a systematic breaking of the observation rules in terms of distance towards the dolphins.





Boat – Dolphin Distances During Active Observation	
Registered Localization of Dolphins while Observed by Touristic Boats	20
Registered Observation Distances	
Touristic Boats, all classes	50
Operator with Dolphin Watching License	45
Privately Operated Boat	3
Operator. without Dolphin Watching License	2
Code of Conduct	
Situation with Boat within the Prohibited 30 m Zone	3
Situation with more than 3 Boats within the 30 - 100 m Zone at the same time	0



Schirok (2021) Universidade Nova de Lisboa, FCSH. Dados: Estudo Reavaliação da capacidade de carga – observação de cetáceos no estuário do Sado, CICS.NOVA, Instituto da Conservação da Natureza e das Florestas (ICNF)

Map 7: Boat – Dolphin distance results with scheme of approaching zones and registered dolphin localizations

The second aspect of the code of conduct we investigated is the maximum number of boats within the 30 - 100 m zone. We wrote a Python code which goes through all observation situations[4] and identifies a situation with more than three boats inside the considered zone. There is no such situation in the data. In the depicted example in the map, we see a situation where two boats are inside the zone and a third one is positioned just outside. The third boat waits outside till it is its turn to enter. The operators communicate with each other and established a collaborative replacement system. Every boat can stay inside the closest observation zone for some time and makes place for other ones if there is a queue. Our data shows that this cooperative system seems to work well. This finding is confirmed in general by the operators reports.

According to the conversations with the operators, their high level of compliance is related to three factors. They are interested in a long-term coexistence of the dolphin population and the dolphin watching industry in the area: Because many of them are born in the area or life there for a long period they feel a sense of responsibility for the biological heritage of the region and they are interested in a sustainable business model in order to maintain their income. The second factor is the awareness of the endangerment of the population and the third factor is the high level of endangerment.

Yet, we also have to consider that the data was collected from a boat of the ICNF (Natural Reserve Authorities). The operators reported, that they were grateful for the presence of the ICNF boat because it supported the proper organization of the observation, just by its presence. From this we can conclude, that without the presence of the boat and thus in situations which are not registered, the observation situation might be more disorganized.

Another aspect we learned through the conversations with the operators which is not represented in the quantitative data, is the non-compliance of privately operated boats of the code of conduct. We have few data of privately operated boats as our focus lies on the MTOs. The problematic with the privately operated boats is that they often do not know the code of conduct and therefore approach the dolphins in an

[4] The individual observation situations are marked with individual waypoints. The illustrated situation on the map is from waypoint number four, from nine waypoints in total on that day which is a relatively high number of waypoints for one day.

inappropriate way. The ICNF has a sensibilization campaign in order to tackle this problematic (Andrade et al., 2014).

IV. Discussion

The mapping of the localizations of dolphin watching boats proves to be a useful tool in order to get a better understanding of the dolphin watching activities in the Sado estuary. Kernel Density mapping can be successfully used to display areas with high dolphin watching intensities (Freitas et al., 2021). Yet, it does not indicate why the operators choose those areas. Are they only following the dolphins or are other factors relevant? The literature suggests that seasickness and sea conditions are major factors for tourist's comfort on vessels (Chuang et al., 2020). We see many boats south of the *Serra da Arrábida* mountain ridge which is an area described as less windy and with less waves. They might go there because of the lesser troubled waters there.

We demonstrate that the operators enter the protected zones of the study area on a regular basis in order to observe the dolphins. This is legal. The operators may enter protected areas they are registered for (Resolução Do Conselho de Ministros n.º 51/2015, 2015). The law on tourism in protected areas states:

> *"Nestas áreas [protegidas], o turismo deve ser sustentável a longo prazo, de forma a assegurar a manutenção dos processos ecológicos essenciais à biodiversidade, e contribuir de maneira positiva para o desenvolvimento económico local, garantindo que a utilização dos recursos não compromete o seu usufruto pelas gerações futuras."* (Resolução Do Conselho de Ministros n.o 51/2015, 2015, p. 4923)

> *"In these [protected] areas, tourism must be sustainable in the long run, in order to guarantee the preservation of ecological processes essential to biodiversity, and contribute positively to local economic development, ensuring that the use of resources does not compromise their benefits for future generations."* (Resolução Do Conselho de Ministros n.o 51/2015, 2015, p. 4923, own translation)

We cannot determine with our data, if the presence of the boats compromises the viability of the dolphin population. The literature suggests that dolphin watching activities might harm the prosperous development of a dolphin population. As we registered repeated boat activity and high boat densities inside the Maritime Park Prof. Luiz Saldanha, a revaluation of the interpretation of the regulation for the case of the Maritime Park could be considered in order to adjust the local practice to the highly endangered status of the local dolphin group.

The kernel density map with a bandwidth of 300m around the boats shows the relevant areas of boat presence from the perspective of the operators and regulator. It is a pragmatical solution which follows the established guidelines and can thus inform the implementation of new management strategies. Yet, it must be considered that for the wellbeing of the dolphin population 300 m is probably not the most appropriate delimitation of the influence radius. Marine cetaceans are disturbed by the noise of boats (Lusseau, 2003). The travel distance of the sound of motor boats does exceed 300 m (Scheifele & Darre, 2005). With sound mapping, the challenge of noise pollution could be addressed (Williams et al., 2015).

Even though the two-dimensional kernel map does work well showing the geographical distribution and intensity of boat localizations, it lacks time sensibility. This is of importance as we are not only interested in geographical hot spots but also in high densities which occur at the same time. One boat coming to the very same spot every time, but only once in a week, looks like a high-density spot on the kernel density map but does not necessarily mean a huge disturbance of the dolphins in that area. We address the problem by the creation of day per day kernel density maps. We win time precision by doing this, but we lose clarity. Yet, actually the day-by-day maps still do not meet the full requirement of time sensible mapping as they do not differentiate between different observation situations during the day. In order to address this, we could map every single observation situation (waypoints) but we would then get an even more complex bundle of maps which would not fulfil the task of mapping - the useful presentation of information. With a statistically relevant dataset at hand, the usage of space-time cubes could be a solution. This technique does identify geographical cluster in the dataset. It furthermore tests, if the cluster do occur repeatedly in the same area or at different points in time (Nakaya & Yano, 2010).

The mapping of the operation area characteristics presents further aspects of the marine touristic operator's geographical pattern. As we only registered boats when they observed dolphins, the bathymetric data is driven by the positioning of the dolphins. Bathymetry is an important indicator for biological dolphin observation. The bathymetry is used to identify different types of dolphin species. The species *Tursiops Truncatus* is mostly searched for and found in waters till 100 m depth in the Mediterranean sea (Gnone et al., 2005). In a study from Madeira, they were found also in deeper waters but still preferred shallow water in general (Dinis et al., 2016). Using the knowledge of the preferred bathymetric areas of dolphins, Marini et al. use the bathymetry to model the occurrence of bottlenose dolphins (2015). In our data sample, the boats and dolphins show a strong preference for areas till 20 m depths. Further research efforts might consider to take advantage of this strong correlation of bathymetry and occurrence of MTOs in boat position modelling efforts.

The second operation area characteristic we investigated, the distance to the home port, is not only related to the dolphin's behaviour. It is anyhow a determining factor for the delimitation of the operation area of the touristic operators. Surprisingly, we did not find studies on this theme. The travel distance of the operators should be considered in management strategies of the touristic activities, the possible implementation of no-boat zones and the planning of new ports.

The compliance with the observation guidelines does not seem to be a major problem in the Sado estuary, as it is in other dolphin watching areas (Sitar et al., 2016). A study from Reunion island shows that dolphins react with more evasive behaviour if the code of conduct is not followed (Quintana Martín-Montalvo et al., 2021). Thus, our results are very positive. Our impression is that the operators which participated in our workshops - the ones which did not participate maybe represent another stance - are aware of the endangered situation of the dolphins and willing to follow protection measures. They showed a collaborative attitude towards the code of conduct and also our research project. It is important to maintain this collaborative atmosphere in order to maintain the high level of compliance of the guidelines and gain support and valuable insider knowledge for the design and implementation of possible new protection measures. Our participative approach which included the operators in the discussion during the workshops probably helps to support this positive and cooperative working atmosphere (Finkler & Higham, 2020).

The high level of compliance to the guidelines is rooted in a sense of responsibility and the knowledge about the high level of endangerment of the dolphin population. Considering the diminishing number of individuals of the group and the difficulty of small groups to survive, even harsher guidelines could be adequate (Gaspar, 2003). With a high level of information among the operators it might be possible that additional voluntary protection measures are adopted (Allen et al., 2007; Duprey et al., 2008).

How can we now interpret the results in order to get a better understanding of the carrying capacity of the dolphin population of the Sado estuary? The literature does suppose negative effects of touristic watching activities, but it is not clear how these effects apply exactly (New et al., 2015). Studies have traditionally only considered the number of registered boats in order to estimate the observation pressure and have not measured the actual boat density in the water (Almunia et al., 2021). We have now a good impression of the touristic boat density in the water but we still do not know how it exactly affects the dolphins. We know where the boats are but we do not exactly know how their sound distributes around the water. We have protected zones in the study area but they are difficult to mark in the water so the frontiers are hard to see, especially for privately operated boats which often do not know the regulation. The protected zones also may be entered by some registered boats and thus do not provide full protection for the dolphins. The only fully protected areas are those, where the boats cannot go: The sandbanks and tidal flats in the estuary. It also should be considered, that protected areas only serve the dolphins when they are in them, which is not always the case.

Kimberly Peters writes that Geographers often try to adapt spatial planning schemes and ideas one to one from the land to the sea. Following Peters, we can delimit protected areas or fenced walkways through reserve areas on land, but hardly in the water. Water is more flexible by nature and so should be the regulation scheme for marine areas (Peters, 2020b). The author describes that a flexible governance structure is applied for commercial shipping in the Bering strait between Alaska and Russia. Instead of exactly delimiting a passage zone, boat operators are informed via new technologies about possible hazards or whales along their way (Peters, 2020a). With Peters we could think of the carrying capacity in marine areas as something flexible. The dolphin population of the Sado estuary will probably not be endangered because of a certain number of registered observation boats. The carrying capacity also depends on the operator's willingness to avoid harassment, their level of information and understanding of the overall situation of the dolphins, the level of endangerment of the population, knowledge about the movements of the other boats and a flexible application of resting zones and -times for the dolphins.

Yet, we have to consider that our data collection was highly influenced by the Covid19 pandemic. Due to the reduced activities during the pandemic, we only observed 23 boats during our field observation, from the total of 46 boats authorized in 2020. So, we assume that in the future the activities will double and that this leads to a doubling of the spatial pressure put on the dolphins. Considering the negative effect of dolphin watching on the wellbeing of a population described in the literature, the very critical state of the group in the Sado estuary and the spatial presence and pressure registered in this study, we have concerns that a full recovery of activities of all 46 boats would favour the evolution of the dolphin group. Further regulation and management measures seem preferable, also from the perspective of the tour operators. Such measures could include the reduction of the total number of boats and replacement with bigger boats or the introduction of fixed observation routes. The measures should support and enable the operators to practice their business in a sustainable way and assure the survival of the dolphins.

V. Conclusion

This project work uses geographical data of dolphin watching boats collected within the research project *Estudo Reavaliação da capacidade de carga – observação de cetáceos no estuário do Sado* (Revaluation of the carrying capacity – Observation of cetaceans in the Sado estuary), collected during the summer of 2020 in the Sado estuary, Portugal. We mostly registered marine touristic operators with dolphin watching license (MTO), but also marine touristic operators without dolphin watching license and privately operated boats in the estuary and the adjacent ocean while they were actively watching dolphins.

Most localizations were registered in the ocean along the peninsula of Tróia which coincides with the areas of highest touristic boat densities. Boat density is represented via a kernel density estimation. In the presentation of the boat density differentiated by the day of registration, we see that there is a high variation of densities and total number of registrations on different days, with one being the lowest and 33 the highest number of localizations. Most MTO data points are in water depths in between one and 20 meters and travel distance between five and 11 km from their home port to the dolphin watching site. We registered no systematic infraction of the dolphin watching guidelines.

The methodology proves to be useful for the registration and analysis of the spatio-temporal pattern of dolphin watching. In coming up data collection campaigns, the registration of the position of the dolphins could be replaced by the registration of the dolphin's reaction to the presence of the boats. As the code of conduct seems to be respected, the reaction data could inform the boats influence on the wellbeing of the dolphins instead. With a statistically more relevant dataset from future campaigns, geo-statistical methods should be applied to analyse the spatio-temporal boat pattern. In order to strengthen the participative character of the project and triangulate the quantitative data, subjective data of the operators should be collected with qualitative methods. Finally, all stakeholders should be involved to discuss future conservation measures in order to strengthen the knowledge basis, compliance of regulation and finding of an appropriate and flexible carrying capacity.

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