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Baseline

Dredging activity in a highly urbanised estuary did not affect the long-term occurrence of Indo-Pacific bottlenose dolphins and long-nosed fur seals

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ABSTRACT

Dredging is an excavation activity used worldwide in marine and freshwater environments to create, deepen, and maintain waterways, harbours, channels, locks, docks, berths, river entrances, and approaches to ports and boat ramps. However, dredging impacts on marine life, including marine mammals (cetaceans, pinnipeds, and sirenians), remain largely unknown. Here we quantified the effect of dredging operations in 2005 and 2019 on the occurrence of Indo-Pacific bottlenose dolphins (*Tursiops aduncus*) and long-nosed fur seals (*Arctocephalus forsteri*) in the Port River estuary, a highly urbanized estuary in Adelaide, South Australia. We applied generalised linear models to two long-term sighting datasets (dolphins: 1992–2020, fur seals: 2010–2020), to analyse changes in sighting rates as a function of dredging operations, season, rainfall, and sea surface temperature. We showed that the fluctuations in both dolphin and fur seal occurrences were not correlated with dredging operations, whereas sea surface temperature and season were stronger predictors of both species sighting rates (with seals more prevalent during the colder months, and dolphins in summer). Given the highly industrial environment of the Port River estuary, it is possible that animals in this area are habituated to high noise levels and therefore were not disturbed by dredging operations. Future research would benefit from analysing short-term effects of dredging operations on behaviour, movement patterns and habitat use to determine effects of possible habitat alteration caused by dredging.

1. Introduction

Marine mammals are subject to human impacts in most parts of the world, especially in heavily populated coastal regions (Avila et al., 2018; Davidson et al., 2012). One prevalent activity in coastal areas is engineering work associated with residential, industrial, and port developments. Port infrastructure is critical to the world's economy and the demand for increasing capacity has seen major port expansions around the globe over the last few decades (Bossley and Woolfall, 2014). The higher shipping rates and the ever-increasing size of commercial and tourist cruise vessels require extensive dredging activities at ports for channel deepening and widening, and to maintain navigation channels and harbour entrances. However, dredging activities are of concern to the conservation of marine environments because of the potential habitat modification and disturbance associated with the removal of substratum from the seafloor and the disposal of soft-bottom material (Erftemeijer and Lewis III, 2006; Erftemeijer et al., 2012; Spearman, 2015; Wenger et al., 2017).

Dredging can increase underwater noise levels (Hoffman, 2012), removal of organisms associated with the seabed (Board and Council, 2002), habitat degradation (Erftemeijer and Lewis III, 2006), contaminant remobilisation, suspended sediments, and sedimentation (Torres et al., 2009), all of which can have potential short- and long-term impacts on marine mammals (Pirotta et al., 2013; Todd et al., 2015). Studies on the effect of dredging activities on marine mammals have mainly focused on short-term impacts on distribution and behaviour of

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odontocetes, such as avoidance and displacement (Hoffman, 2012; Marley et al., 2017; Pirotta et al., 2013; Todd et al., 2015). For example, dredging operations over three years in the Aberdeen harbour, Scotland, resulted in common bottlenose dolphins (*Tursiops truncatus*) spending less time in the area as the intensity of dredging activity increased (Pirotta et al., 2013). However, the short- and long-term behavioural responses of marine mammals to dredging activities remain largely unknown. Because the impacts of dredging appear to be species and location-specific, depending on multiple factors such as the duration and type of dredging equipment involved, generalisations between sites are difficult and long-term studies are needed to identify potential population-level consequences resulting from long-term responses (Todd et al., 2015).

Besides anthropological impacts such as dredging, environmental factors can also influence marine mammal abundance. Variables that vary temporally such as seasonal rainfall and changes in sea surface temperature have been shown to affect dolphin abundance, with lower numbers during periods of high rainfall and lower sea surface temperature (Lin et al., 2021; Lin et al., 2015; Sprogis et al., 2018). Most research on fur seal abundance has been done at breeding colonies (Shaughnessy et al., 2005; Shaughnessy and Goldsworthy, 2015), thus little is known about how environmental variables influence abundance

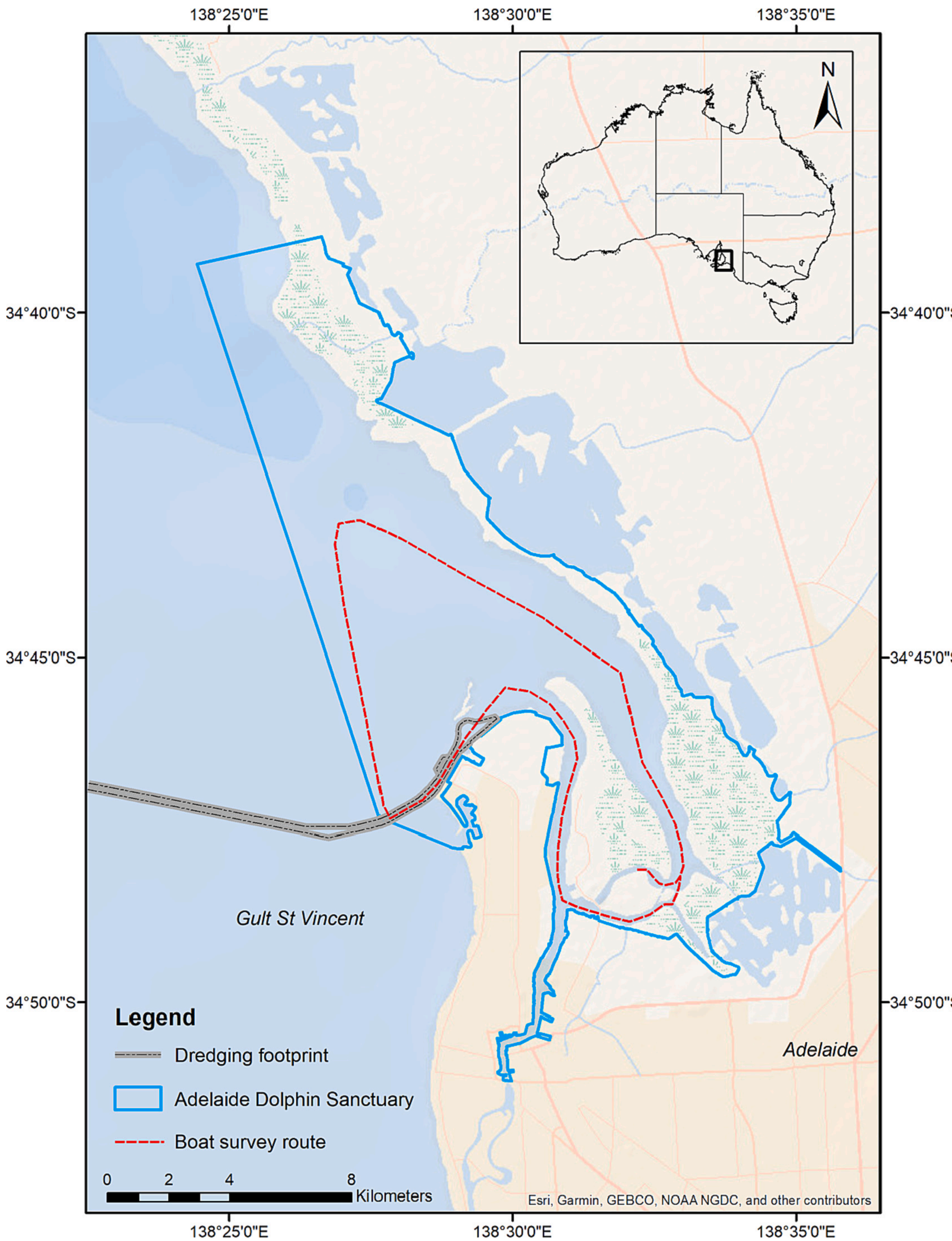

Fig. 1. Map of the Port River estuary, South Australia, showing the boundary of the Adelaide Dolphin Sanctuary, the survey route, and the dredging location. Inset map indicates position of study site in relation to Australia.

at non-breeding haul-out sites. Previous research suggests that environmental effects on abundance at haul-out sites are likely site-specific and difficult to generalise (Burleigh et al., 2008).

Indo-Pacific bottlenose dolphins (*Tursiops aduncus*, hereafter 'dolphins') and long-nosed fur seals (*Arctocephalus forsteri*, hereafter 'fur seals') are protected species under South Australian law. In the Port River estuary, South Australia, dolphins are present year-round with an estimated 6% annual increase in sightings since the 1980s (Bossley et al., 2017). Fur seal numbers are strongly seasonal, with a maximum of up to 80 in the winter months (Shaughnessy et al., 2017). In response to a number of deliberate attacks on dolphins in the area, the Adelaide Dolphin Sanctuary (Fig. 1) was established in the Port River estuary by act of parliament in 2005 (The South Australian Government Gazette 2005). The legislation establishing the Adelaide Dolphin Sanctuary requires protection of both the dolphins and their habitat by further improving the water quality, promote ecologically sustainable development, and raising public awareness of the importance of the area (Bossley et al., 2017; South Australian Government, 2005; Techera, 2016).

Coastal developments, expansion of port facilities and associated dredging works are likely to increase in the future to accommodate large-capacity vessels and higher shipping rates (Haralambides, 2019). Thus, understanding the effects of dredging activities on upper-level predators such as marine mammals is needed to manage and minimise impacts and maintain the structure, dynamics, and function of coastal ecosystems. In this study, we use a long-term (29 years) monitoring dataset on the presence of dolphins and a 9-year monitoring dataset on the presence of fur seals in the Adelaide Dolphin Sanctuary to assess the effect of dredging operations in the area in 2005 and 2019 on sighting numbers. In detail, we test the hypotheses that i) sighting numbers will decrease with dredging activity, and ii) sea surface temperature and season will be the main environmental variables explaining changes in sighting trends.

2. Methods

2.1. Study area

Adelaide, the capital of the state of South Australia, is a city of 1.3 million people located on the southern coast of Australia (34°S, 138°E; Fig. 1). South Australia's main port is on the lower reaches of Adelaide's Port River and is known as Outer Harbour. The river has undergone substantial anthropogenic changes since European colonisation in the mid-1900s. These include industrial and sewage discharges into the river, riverfront reclamation works, and dredging. Rock seawalls have been built on both the northern and southern limits of the river.

The physical characteristics of the Port River estuary area vary in terms of exposure to wave energy (open to Gulf St Vincent to totally protected), bathymetry (from 14 m to intertidal), substrate characteristic (sand or mud) and the degree of human modification (from barely to heavily modified). The biological characteristics reflect the physical heterogeneity, most clearly demonstrated by the presence or absence of mangroves and seagrasses. The Port River estuary is considered an important nursery for several commercially caught fin fish species (Jones, 1984). Outer Harbour was established in 1904 (Couper-Smartt and Courtney, 2003) and the ecology of the area has been heavily modified by human activities with the construction of wharves on the southern side of the river and breakwaters on the north. The breakwaters have resulted in the accumulation of sand from the longshore drift along the Adelaide coastline, as well as the formation of an extensive sandbar to the east of the northern breakwater, which is being colonised by mangroves. Introduced species include the fan worm *Sabella spallanzanii*, the ascidian *Ciona intestinalis*, and the brown alga *Caulerpa racemosa*. Macroalgae, invertebrates and fish characteristic of temperate reefs occupy the rocky breakwaters (Bossley, personal observations).

Dredging was implemented in 2005 and 2019 to accommodate for Panamax- and New Panmax-size vessels (290 and 366 m length, respectively) (Boskalis Dredge Management Plan, 2019), Fig. 1. Dredging involved the use of a trailing suction hopper dredger for softer material and a backhoe dredge for harder material. While seagrass at the dredge site recovered after the first dredging, there were changes in invertebrate assemblages at the dump site (Wiltshire and Tanner, 2016). An impact study of the second dredging focusing on seagrass coverage and turbidity found that four hectares of seagrass were lost as a direct result of being dug out by the dredge, however, there was no effect on seagrass cover resulting from turbidity/sedimentation (Gaylard et al., 2020). Seagrass has been recognised as a key habitat sustaining marine megafauna as it provides important foraging grounds and supports critical species at the base of the food web (Sievers et al., 2019). Changes in seagrass abundance can potentially alter marine megafauna abundance and habitat use (Nowicki et al., 2019).

2.2. Data collection

We collected systemic data on the presence of dolphins (since 1990) and fur seals (since 2004) in the Port River estuary in Adelaide, South Australia (Fig. 1). Data were collected from a variety of power boats ranging from 4 to 6 m. Surveys were conducted opportunistically throughout the year but only in Beaufort Sea states <3. The research boat followed a predetermined survey route of approximately 40 km in length including the dredged portion of the Port River, as well as areas to the north of the dredging (see Fig. 1). Each survey was defined as traversing the full route with one survey per day, each survey lasting between three and four hours, depending on the number of dolphins encountered.

During each survey, one to six observers scanned an arc of 120° forward of the vessel at a speed from 4 to 10 knots, looking for dolphins. Previous analysis demonstrated no correlation between the number of observers on board the research vessel and the number of dolphin group sighted per survey (Bossley et al., 2017). When a dolphin or a dolphin group (i.e., dolphins within an approximately 100 m radius) were sighted, the vessel's speed was reduced or stopped altogether to avoid disturbing the animals as state legislation requires boats to approach no closer than 50 m. For each dolphin group sighting, data recorded included time, group size, Beaufort Sea State, and geographic location obtained by Global Positioning System (GPS). Prior to 1995, GPS technology was not used, and dolphin group sighting locations were mapped using triangulation methods and landmarks that were later converted to southern and easterly coordinates. During dolphin sightings, photographs of the dorsal fin of individual animals were taken for photo identification based on distinguishing marks (e.g., the shape, notches, and scars) (Würsig and Jefferson, 1990). Photographic records were used to avoid counting the same individual twice during a survey. Note that no data were collected to the south and west of the dredging area. For dolphins, we focused our analyses on the first dredging (2005) as our dataset allowed the most balanced analysis for this purpose. The final dataset ranged from 1992–2020 as previous to 1992, data for environmental variables were not available.

Fur seals in the Port River estuary haul out on the northern breakwater. We counted the individuals on land, as well as those in the water adjacent to the breakwater, from the research vessel. As most seals were hauled out on land and almost always immobile, double counts are unlikely to have occurred. However, individuals were not tagged, therefore we could not determine individual identities. As sightings of fur seals have been collected in the outer harbour since 2004 (Shaughnessy et al., 2017), we did not have sufficient data from before the dredging in 2005 to run our analyses. Therefore, we only used data from 2010 onwards to assess the impact of dredging activity in 2019 and assumed that any potential impacts on fur seal numbers from the 2005 dredging activity had ceased by then.

For each month of the surveys, we calculated mean monthly values from daily rainfall data collected at the Seaton weather station from the

Australian Bureau of Meteorology (http://www.bom.gov.au), as well as daily sea surface temperature (SST) data downloaded from the Integrated Marine Observing System database (IMOS) (https://portal.aodn.org.au/search) at the closest location available to the study site (0.02 × 0.02°, latitude: 34.7631°S, longitude: 138.4765°E).

2.3. Data analysis

We first standardised our dataset (since the survey effort was not equal over time) by calculating the average number of dolphins and fur seals sighted per survey for each month. We then explored the general trend in our data by fitting a Locally Weighted Scatterplot Smoothing function (LOWESS) to the log (see justification for log transformation below) of the monthly mean number of dolphin and fur seal sightings as a function of the month of the survey (Fig. 2). LOWESS is a non-parametric regression technique (i.e., no *a-priori* about the distribution of the data) that attempts to capture the general patterns in the response variable while reducing the noise and making minimal assumption about the relationships among variables. As dolphin and fur seal numbers can potentially be influenced by a range of factors including anthropogenic activities and environmental variables, we used generalised linear models (GLM, Agresti, 2015) to analyse the relationship between a suite of explanatory variables and both dolphin and fur seal numbers using the 'stats' package in R version 4.1.0 (R Core Team, 2022). GLMs offer a flexible approach to data analysis as they provide a unified theory of modelling that encompasses the most important models for both continuous and discrete response variables (that can have any form of exponential family distribution). We connected the random (i.e., the response variable) and systematic (i.e., linear predictor and explanatory variables) component of our GLM using a gaussian distribution with an identity link function because of the specific nature of our datasets. Both dolphins and fur seals are highly mobile species, sometimes moving in groups, which makes it difficult to determine a specific distribution for the response variables and led to use a more empirical approach by (i) log transforming the data to stabilize the variance in the time series (hereafter "dolphins and fur seals sighted") and meet the assumption of normality, and (ii) using a GLM with a gaussian distribution with an identity link function (Agresti, 2015).

Our predictive variables were the two continuous variables mean monthly rainfall and mean monthly sea surface temperature, and season (factor with four levels based on austral seasons: December–February = summer, March–May = autumn, June–August = winter, September–November = spring). We also tested the relative effect of the dredging and the change in population increase showed by the LOWESS analyses for both dolphins and fur seals (i.e., inflexion point in the LOWESS, 6 years post- and 3 years prior- dredging, respectively, see Fig. 2). To characterise this differential increase in species population and potential dredging impact, we fitted three linear regressions to the time series (called v1, v2 and v3) adjusted on either side of these inflexion points and dredging (see Fig. 2) that we then used as predictors in the GLM analysis.

Using all possible combinations of variables, we constructed a total of 36 GLMs for dolphins and fur seals each. We selected the best-fitting model based on the corrected Akaike's information criterion weights adjusted for small sample size ($wAIC_c$) (Burnham et al., 2011) and tested this model for the effect of all possible interactions among its predictor variables (except interactions of v1, v2 and v3 with each other). We compared these new models with the top-ranked model without interactions using $wAIC_c$ to select the final top-ranked model. We checked the final models for normality, heteroskedasticity, potential patterns and temporal autocorrelation (using an autocorrelation function) in the residuals (Wood, 2017). From these final models, we evaluated the relative importance of each predictor variable by calculating the change in goodness of fit (i.e., the adjusted amount of deviance accounted for by the GLM, Weisberg, 2005) when this predictor is left out of the full model. This procedure is equivalent to a sensitivity analysis of the final model to each of its predictors to quantify and rank the relative importance of each predictor in the full model.

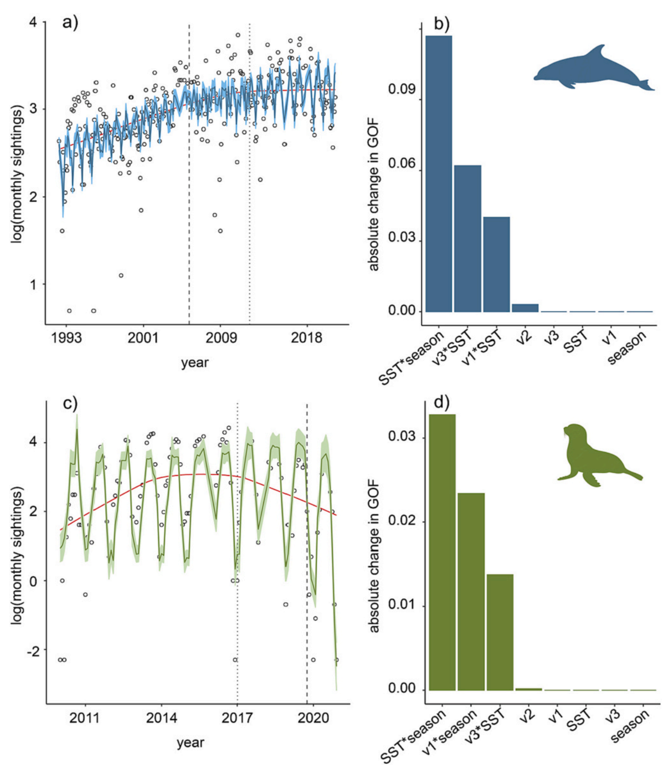

Fig. 2. Final generalised linear model (GLM) for bottlenose dolphins *Tursiops aduncus* (a & b) and long-nosed fur seals *Arctocephalus forsteri* (c & d). Points show log-transformed monthly averages of sightings, red line represents LOWESS smoother. Dashed line indicates time of dredging (2005 for dolphins, 2019 for fur seals), dotted lines mark changes in population trend used to determine variables v1, v2 and v3 (see Methods). Variable importance is shown as absolute change in goodness of fit (GOF) in panels b) and d). The final model for dolphins and fur seals explained 40.2 % and 70 % of the deviance, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

3. Results

The sampling effort over 876 days between 1992 and 2020 resulted in 17,897 dolphin sightings, with an average of 2.9 surveys per month (SD = 1.7, range 1 – 10). The top-ranked model retained v1, v2 and v3 (the linear regressions representing periods before and after the 2005 dredging activity, Fig. 2a) as well as sea surface temperature, season, and the interactions of each v1, v3 and season with sea surface temperature, explaining 40.2% of the deviance (see Table 1 for the three best fitting models). However, of these variables, only the interactions had high importance for the model fit, with the interaction between sea surface temperature and season being the most important predictor (Fig. 2b). Dredging did not affect dolphin sightings. These results indicate that seasonal climate is an important driver of dolphin numbers in the Adelaide Dolphin Sanctuary. While dolphin sightings generally increased throughout the study period, there is a clear seasonal pattern with more sightings during warmer months and with increased sea surface temperature in spring and winter, but fewer sightings with increased temperature in summer. The rate of increase in sightings was lower from 2012 onwards.

For fur seals, a total of 416 surveys done between 2010 and 2020 resulted in 6963 sightings. The model that best explained our data retained v1, v2 and v3 (the linear regressions representing periods before and after the 2019 dredging activity, Fig. 2c) as well as sea

Table 1
Generalised linear models (GLMs) for a) Indo-pacific bottlenose dolphin (*Tursiops aduncus*) and b) long-nosed fur seal (*Arctocephalus forsteri*) sightings in the Port River estuary. The top-ranked model (shaded in grey) for both species retained mean monthly sea surface temperature (SST) fitted with an interaction for austral season (Fig. 2). Variables v1, v2 and v3 are linear regressions representing periods before and after the dredging activity, respectively. Significant variables in each model are given in bold, number of parameters (k) are given for final models. % DE = % deviance explained; ΔAIC = difference in Akaike's information criterion (AICc) of the current and top-ranked model; *w*AICc = AICc weight.

#	Model	k	% DE	ΔAICc	*w*AICc
a) bottlenose dolphin *Tursiops aduncus*					
1	~ **v1** + v2 + v3 + SST + **season** + (v1*SST) + **(v3*SST)** + **(SST*season)**	14	40.2	-	0.012
2	~ **v1** + v2 + v3 + SST + **season** + (v3 * SST) + **(SST * season)**	13	39.5	1.00	0.007
3	~ **v1** + v2 + v3 + SST + **season** + (v2 * season) + **(SST * season)**	15	40.4	1.21	0.00
b) fur seal *Arctocephalus forsteri*					
1	~ **v1** + v2 + v3 + **meanSST** + **season** + **(v1 * season)** + **(v3 * meanSST)** + **(meanSST * season)**	16	69.7	-	0.023
2	~ v1 + v2 + v3 + **SST** + season + **(v3 * SST)** + **(SST * season)**	13	67.3	0.41	0.018
3	~ v1 + v2 + v3 + SST + **season** + (v1 * SST) + **(v1 * season)** + **(v3 * SST)** + **(SST * season)**	17	70.1	1.23	0.012

surface temperature, season, and the interactions of v1 with season, v3 with sea surface temperature, and season with sea surface temperature, explaining 69.7 % of the deviance (Table 1). Dredging only had an effect on seal sightings when interacting with sea surface temperature (GLM coefficient = -0.7×10^{-4}), with a positive correlation between the two variables (i.e., Spearman's rho = 0.1). As in the dolphin model, the interaction terms explained most of the variance in our data, with the interaction between sea surface temperature and season being most important (Fig. 2d). Fur seal sightings increased throughout the study period and declined following a peak in 2016 (Fig. 2c).

4. Discussion

We analysed long-term datasets for Indo-Pacific bottlenose dolphins and long-nosed fur seals to determine effects of dredging activity on sighting numbers in the Port River estuary, South Australia. While both species exhibited fluctuations in sighting numbers, declines did not coincide with dredging activity. Instead, sightings for dolphins and fur seals were strongly linked to sea surface temperature and season. Dolphin sightings increased steadily throughout the study period, which could be due to an improvement of overall habitat quality in the estuary (Bossley et al. 2017). However, the rate of increase declined at around 2012 (Fig. 2). This reduction in increase rate occurred ~6 years after completion of the first dredging activity and thus is unlikely to be a direct function of the dredging. Other cumulative natural and anthropogenic pressures or natural demographic stochasticity may be responsible. In recent years, there has been an increase in calf mortality and dolphin deaths recorded in the sanctuary (Crook, 2020; Kirkwood et al., 2022), which could explain the decline in the rate of increase in sightings. While an investigation of potential reasons is underway, no specific cause has been isolated thus far.

Dolphin sighting numbers increased with increasing sea surface temperature in winter and spring, which are the seasons where the water in the estuary is the coldest. Temperature can affect dolphins both directly, on a physiological level, and indirectly, as it can influence prey availability. Although the effect of temperature is likely habitat specific, previous studies in other locations have shown higher abundance of bottlenose dolphins in the warmer months (e.g., Barco et al., 1999). Furthermore, bottlenose dolphin numbers in Spencer Gulf and Gulf St Vincent have been estimated to be slightly higher in summer/autumn than in winter/spring (Bilgmann et al., 2019), which could confirm a preference for warmer waters, particularly in the colder months, in our study area. Our results show that during summer, sightings were negatively correlated with sea surface temperature, indicating that dolphins may avoid the warm estuary waters during extreme summer temperatures. Long-term demographic data on Indo-Pacific bottlenose dolphins in Shark Bay, Western Australia, showed up to 12.2% population declines in survival following marine heatwaves (Wild et al., 2019).

Dredging has the potential to impact coastal dolphins in different ways, but these impacts are species and site-specific. Findings of other studies on the impact of dredging on odontocetes have focused on short-term changes and show varying results, from short-term avoidance (Diederichs et al., 2010; Pirotta et al., 2013) to no apparent (Hoffman, 2012) or inconclusive effects (Marley et al., 2017). While we found no long-term effect of dredging on dolphin sightings in the Port River Estuary and Adelaide Dolphin Sanctuary over a 29-year period, we did not examine short-term behavioural effects of dredging activity on dolphins, such as fine-scale changes in habitat use. Future research, particular in the case of further dredging activities, would benefit from exploring finer spatial and temporal scales to investigate short-term changes in habitat use and behaviour.

The most likely direct effect dredging may have on dolphins is linked to the noise produced by the dredging activity. Overall, noise emitted by dredging activities is broadband, with most energy below 1 kHz and thus unlikely to cause damage to dolphins' or seals' auditory systems. However, marine mammals are sensitive to noise as they use sound for communication, navigation and to locate prey (Nowacek et al., 2007; Richardson et al., 1995). Anthropogenic noise can become a concern for marine mammals when it falls within the auditory bandwidth (i.e., hearing sensitivity) of the species in question (Erbe et al., 2016). Noise produced by dredging activities depends on the material dredged and the dredging type (Todd et al., 2015). The two types used in the Port River estuary were backhoe dredging, which is one of the quietest types of marine dredgers, and trailing suction hopper dredgers, which cause considerably more noise (Robinson et al., 2012; Thomsen et al., 2009). Based on existing literature these dredgers likely emitted noise in the range of 163–179 dB with a bandwidth of 3 Hz–200 kHz (backhoe dredger, Nedwell et al., 2008; Reine et al., 2014) and 190 dB with a bandwidth of 31 Hz–40 kHz (trailing suction hopper dredger, Robinson et al., 2012).

Bottlenose dolphins have the ability to hear and produce sounds over a range of 150 kHz and sounds below 30 kHz are commonly used by many odontocete species for communication and echolocation, thus masking and behavioural changes are possible (Jones et al., 2020; Todd et al., 2015). It should be noted that many other activities occur concurrently with dredging (e.g., shipping noise and on-shore construction activities) and thus dolphins are exposed to cumulative noise underwater from different activities. The Port River estuary is subject to high shipping activity, and dolphins in this area are likely accustomed to high levels of noise produced by vessel traffic and industrial operations (Bossley et al., 2017). It is possible that dolphins in the estuary have become habituated to elevated noise levels over time, and therefore showed no long-term avoidance of the study area.

Besides the establishment of the Adelaide Dolphin Sanctuary and the dredging activities, several changes to the Port River estuary environment occurred during the period 2000–2020. These include a substantial reduction of industrial discharge into the Port River and an overall improvement in water quality over time, with nitrogen concentration (used as a proxy for water quality) in the inner estuary decreasing by 50% between 1997 and 2008 (Bossley et al., 2017). While these environmental improvements may explain the increase in dolphin sightings over time, they may also have masked any negative impact of dredging on marine mammal usage of the area. Besides the dredging activity which occurred temporarily in 2005 and 2019, the Port River estuary is subject to a number of other anthropogenic environmental impacts including commercial and recreational fishing, industrial shipping, and recreational boating (Bossley et al., 2017).

Fur seal numbers in Adelaide's outer harbour have been increasing steadily since 2010 (Fig. 2c, also discussed in Shaughnessy et al., 2017). This was concurrent with increased pup numbers at the nearest breeding colonies and thus has been attributed to a general population recovery (Shaughnessy et al., 2017; Shaughnessy and Goldsworthy, 2015). As noted in Shaughnessy et al. (2017), fur seal sightings in Adelaide's outer harbour strongly vary with the seasons with a peak in number of individuals in September each year and a drop during the summer months, likely due to breeding dynamics and animals moving to nearby breeding colonies (Shaughnessy et al., 2017).

As pinnipeds use sound for social interactions including mating behaviour (Schusterman and Van Parijs, 2003), dredging noise could potentially disturb fur seals, particularly if it occurs close to breeding areas. Although not specific to dredging activity, grey seal (*Halichoerus grypus*) presence was negatively correlated with high construction vessel traffic in Ireland (Anderwald et al., 2013). Hawaiian monk seals (*Monachus schauinslandi*) did not seem disturbed by dredging activity around Tern Island, USA (Gilmartin, 2003). In this study, data were collected at a haul-out site with no known breeding interactions (Shaughnessy et al., 2017). We did not find sightings to be impacted by the 2019 dredging activity, but the interaction between sea surface temperature and dredging in our results seems to suggest seal sightings decrease post dredging with increasing sea surface temperature. However, we will need data for more years of post-dredging to increase the statistical power of our analysis and explore this interaction further. Overall, our results indicate that since 2016, numbers of fur seals sighted in the outer harbour have decreased (Fig. 2). At this stage, it is unclear what caused this decrease and if there are similar population-level developments in other haul-out sites or breeding colonies in South Australia.

5. Conclusion

While our study shows a slower rate of increase in dolphin sightings since 2012, as well as a decline in fur seal numbers sighted in the outer harbour since 2016, none of these changes appear to be directly linked to dredging activity. It is possible that concurrent improvements of the dolphin habitat in the Port River estuary have outweighed any negative impacts of dredging, resulting in an overall increase in dolphin numbers over the whole study area. Future studies should aim to analyse behaviour, movement patterns and habitat use at a fine spatial scale, as well as determining sediment quality in areas subject to dredging activities, to assess possible habitat alteration caused by dredging.

CRediT authorship contribution statement

Mike I. Bossley: Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – review & editing, Funding acquisition. **Aude Steiner:** Conceptualization, Data curation, Writing – review & editing. **Guido J. Parra:** Conceptualization, Methodology, Writing – review & editing, Visualization. **Frédérik Saltré:** Methodology, Formal analysis, Writing – review & editing, Visualization. **Katharina J. Peters:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Mike Bossley reports financial support for part of this study was provided by Flinders Ports. However, Flinders Ports had no involvement in analysis and manuscript writing.

Data availability

Data will be made available on request.

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