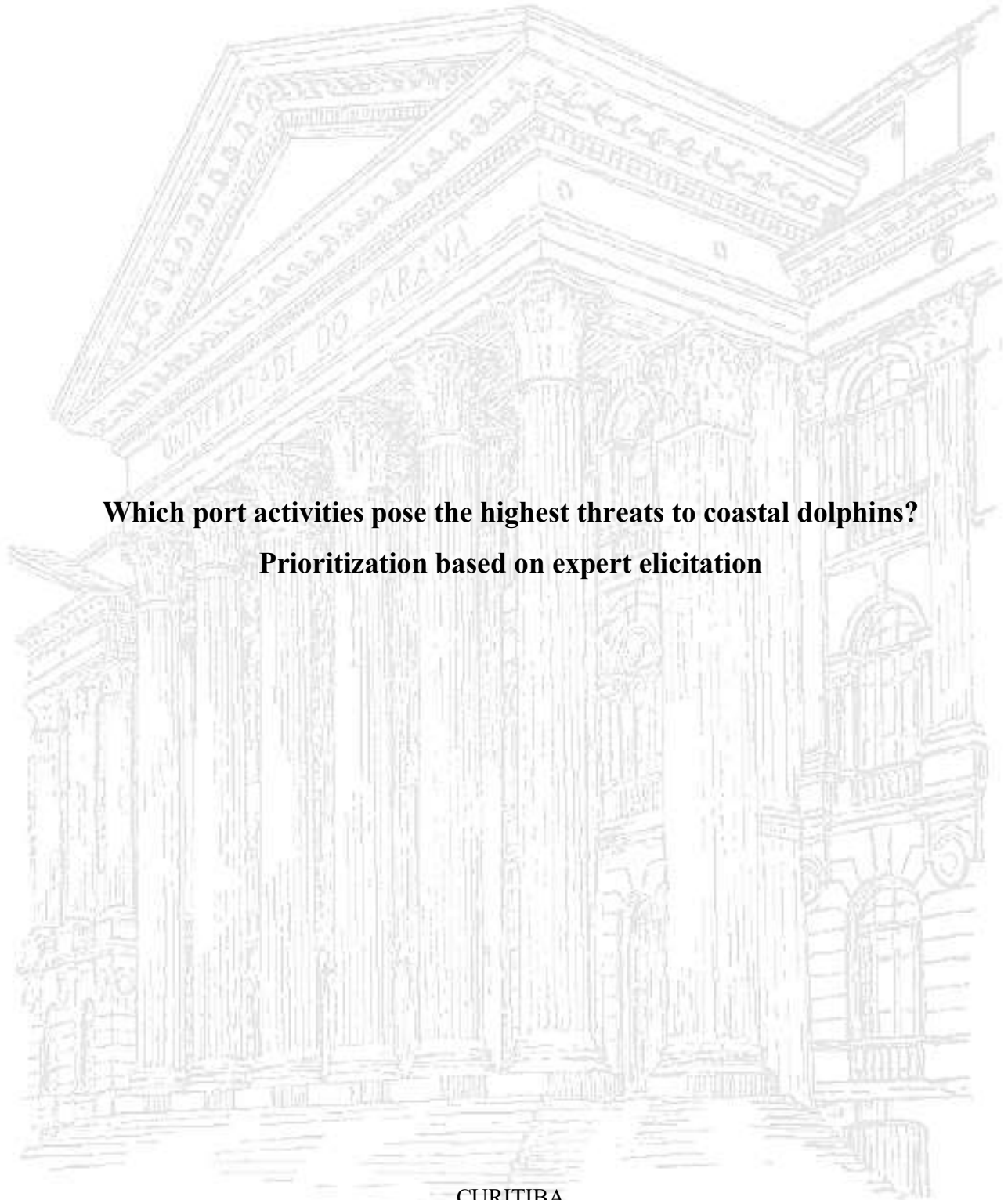


UNIVERSIDADE FEDERAL DO PARANÁ



Which port activities pose the highest threats to coastal dolphins?

Prioritization based on expert elicitation

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Which port activities pose the highest threats to coastal dolphins?

Prioritization based on expert elicitation

Quais atividades portuárias são consideradas as maiores ameaças para os golfinhos costeiros?

Priorização baseada na opinião de especialistas

Trabalho de Conclusão de Curso de Especialização
em Análise Ambiental, Departamento de Geografia
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Resumo

A globalização causa um aumento nas demandas econômicas e, conseqüentemente, no desenvolvimento de áreas portuárias e do tráfego marítimo. Essa expansão global de portos gera uma ampla gama de atividades portuárias, que podem impactar o ambiente marinho direta e indiretamente de várias maneiras. Estas vias de impacto são complexas e sinérgicas e representam um desafio para a gestão ambiental dos portos. A fim de integrar o desenvolvimento socioeconômico e a conservação ambiental, é crucial priorizar quais impactos lidar primeiro. Os impactos das atividades antropogênicas na saúde e no funcionamento do ecossistema marinho podem ser avaliados e monitorados usando golfinhos costeiros como sentinelas ambientais. Neste estudo, a elicitação de especialistas foi usada para fornecer insights sobre quais atividades portuárias são percebidas como tendo o maior impacto sobre os golfinhos costeiros e por quê. Os impactos relativos de seis atividades portuárias foram comparados: dragagem, bate-estaca, tráfego marítimo, explosões subaquáticas, acidentes ambientais e desenvolvimento de infraestrutura. Foi solicitado aos especialistas que avaliassem os impactos das atividades portuárias aos golfinhos costeiros por meio de uma pesquisa online composta por três partes: (1) avaliação da vulnerabilidade, atribuindo pontuações à escala geográfica, frequência, impacto funcional e resiliência de cada atividade portuária; (2) avaliação do nível de impacto, atribuindo categorias de conseqüências a vários níveis de impacto de cada atividade portuária; (3) avaliação de impacto relativo, em que todas as atividades portuárias foram comparadas através de comparações pareadas. Os 57 especialistas, de 17 países diferentes, que contribuíram para a pesquisa indicaram acidentes ambientais e desenvolvimento de infraestrutura como as atividades de maior impacto para os golfinhos costeiros. Ambos geram altos níveis de degradação de habitats e poluição química, o que causa um alto impacto funcional no ecossistema, enquanto os golfinhos costeiros também são vistos como tendo baixa resiliência a ambos os estressores. Destruição do habitat causada pela dragagem, acidentes ambientais e desenvolvimento de infra-estrutura; e poluição sonora gerada por explosões submarinas e aumento do tráfego marítimo são percebidos como os impactos com as piores conseqüências para os golfinhos costeiros. Esses resultados fornecem orientações valiosas para a priorização de ações de gestão ambiental nas áreas portuárias. No entanto, informações baseadas em elicitação de especialistas devem sempre ser interpretadas com cuidado, uma vez que todos os resultados são um reflexo do conhecimento e da experiência dos entrevistados. Portanto, avaliamos a incerteza de forma explícita ao longo de todo o levantamento, através do qual emergiu a existência de uma lacuna de conhecimento em relação aos impactos causados pelas atividades de bate-estaca em áreas portuárias. Além disso, isso revelou que os entrevistados tendem a avaliar as atividades portuárias sobre as quais têm menos conhecimento como o menos impactante para os golfinhos costeiros. Os rankings de atividades portuárias obtidos fornecem não apenas insights sobre o estado atual de conhecimento das ameaças, impactos e conseqüências geradas por essas atividades, mas também um apoio crucial para a tomada de decisões na gestão ambiental das áreas portuárias, ajudando os gestores a priorizar suas decisões e recursos.

Palavras-chave: portos, avaliação de impacto, ameaças, mamíferos marinhos, conservação marinha

Abstract

Globalization causes a significant increase in economic demands and consequently the development of port areas and marine traffic. This global port expansion generates a wide array of port activities, which might impact the marine environment directly and indirectly in a variety of ways. These complex and synergistic impact pathways pose a challenge for the environmental management of ports. In order to integrate socio-economic development and environmental conservation, it is crucial to prioritize which impacts to deal with first. The impacts of anthropogenic activities to the marine ecosystem health and functioning can be assessed and monitored using coastal dolphins as environmental sentinels. In this study, expert elicitation has been used to provide insights into which port activities are perceived to have the highest impact on coastal dolphins, and why. The relative impacts of six port activities have been compared: dredging, port pile driving, marine traffic, underwater explosions, environmental accidents, and infrastructure development. Experts were asked to assess the impacts of port activities to coastal dolphins through an online survey consisting of three parts: (1) vulnerability assessment, assigning scores to the scale, frequency, functional impact and resilience of each port activity; (2) impact level assessment, assigning consequence categories to several impact levels of each port activity; (3) relative impact assessment, in which all port activities were compared through pairwise comparisons. The 57 experts, from 17 different countries, that contributed to the survey indicated environmental accidents and infrastructure development as the activities with the highest impact for coastal dolphins. Both generate high levels of habitat degradation and chemical pollution, which causes a high functional impact in the ecosystem, whilst coastal dolphins are perceived to have a low resilience to both stressors. Habitat destruction caused by dredging, environmental accidents and infrastructure development; and noise pollution generated by underwater explosions and increased marine traffic are perceived to be the impacts with the worst consequences for coastal dolphins. These results provide valuable guidance for the prioritization of environmental management actions in port areas. However, information based on expert elicitation should always be interpreted with care, since all results are a reflection of the respondents' knowledge and experience. Therefore, we assessed uncertainty explicitly throughout the entire survey, by which emerged the existence of a knowledge gap regarding the impacts caused by port pile driving. Furthermore, this revealed that respondents tend to assess port activities about which they have less knowledge as least impacting for coastal dolphins. The obtained rankings of port activities provide not only insights in the current state of knowledge of threats, impacts and consequences generated by these activities, but also crucial support for decision-making in the environmental management of port areas, helping managers to prioritize their decisions and resources.

Keywords: port, impact assessment, threats, marine mammals, marine conservation

Highlights

- Ports activities impact the marine environment directly and indirectly. Coastal dolphin species are environmental sentinels, reflecting port impacts to the marine ecosystem functioning and health.
- Expert elicitation provided insights on which port activities are perceived to have the highest impact on coastal dolphins and their habitat
- Environmental accidents and infrastructure development are perceived to have the highest impact on coastal dolphin populations and their habitat, generating high levels of habitat degradation and chemical pollution. Both activities cause a high functional impact in the ecosystem, whilst coastal dolphins are perceived to have a low resilience to these activities.
- A knowledge gap exists regarding the impacts on coastal dolphins generated by port pile driving. The impacts, effects and consequences of port pile driving for coastal dolphins should be addressed in future research.
- Based on the interviews, respondents tend to evaluate the port activities about which they have more knowledge as more impactful.
- The comparative impact assessment of port activities enables to evaluate synergistic impacts and the prioritization of management actions, providing support for decision-making within the environmental management of port areas.

Introduction

Globalization and the associated economic growth cause a significant increase in marine traffic and coastal development, with ship transport accounting for ninety percent of the international trade volume^{1,2}. The construction and expansion of port areas are essential to support this type of social and economic growth^{3,4}. Consequently, there is an intense worldwide increase in port development, which generates a wide array of activities that might impact the marine environment both directly and indirectly^{3,5}. Some of the impacts and consequences of these port activities on the marine environment and resident marine fauna are being investigated, such as underwater noise^{6,7}, pollution⁸⁻¹⁰, and hydrodynamic changes^{11,12}. However, there still exist many uncertainties¹³⁻¹⁵, which hamper optimal environmental management of port areas. Furthermore, the cumulative and synergistic impacts of port areas and the effects on the marine environment and fauna are still unclear^{13,16}.

In order to allow well informed environmental management decisions of port areas, a clear and comprehensive evaluation of the impacts caused by port activities to the marine environment is necessary. To assess the impacts, effects and consequences of these anthropogenic activities for the marine environment, some marine fauna species can be used as environmental sentinels that function as indicators for the marine ecosystem health¹⁷⁻²⁰. Ports are often located in sheltered estuarine areas¹¹, which are essential habitats for several coastal dolphin species. Due to this inevitable overlap of port areas with habitats used by coastal dolphins, port activities are likely influencing dolphin populations and their habitat directly and indirectly.-

Coastal dolphin species are prime environmental sentinels and indicators for ecosystem health and functioning because of their long life-spans, long residence time in coastal areas, low reproductive rate, and their position at the top of the trophic chain¹⁹. Apart from their changing health conditions, these species can be used as environmental sentinels because of their behavioural responses to anthropogenic stressors, such as shifts in distribution, habitat use, social and foraging behaviour, breathing patterns, etc.²¹. Additionally, due to their ecological characteristics, coastal dolphins concentrate contaminants through both bioaccumulation and biomagnification^{17,20}, and integrate broadly across the ecosystem in terms of exposure to environmental impacts²⁰, which might cause them to respond to the whole of cumulative and synergistic impacts generated by the installation and operation of ports.

The assessment of the cumulative impact of anthropogenic activities generated by ports for the marine environment, and coastal dolphins in particular, is crucial to inform strategic planning and marine conservation²². In order to evaluate cumulative impact of ports, it is essential to investigate which port activities are present and which are the relative impacts caused by these activities, to reveal which port activities may require prioritized management actions^{23,24}. Therefore, there is the need to systematically investigate how each port activity can individually affect the present coastal dolphin

populations, and what is the relative magnitude, intensity and duration of the impacts. This systematic comparison among port activities allows to compare the relative ecological impacts of each of the activities and provides support for threat prioritisation and environmental management decision-making.

Port activities are inevitably impacting coastal dolphins around the globe. Nevertheless, to our knowledge, no study has systematically investigated the relative impact of each of these port activities on coastal dolphins, making it challenging for managers to prioritize their decisions and resources. Until now, most studies are mainly focussing on the threat and impact assessment of one port activity individually affecting dolphin populations, for example increased marine traffic ²⁵⁻²⁷, dredging ¹⁵, infrastructure development ²⁸. This variety of port activities generates a multitude of threats to coastal dolphins. For example, pollution and traffic-related impacts are globally among the principal threats to marine mammals ²⁹. However, the lack of comparative assessment of different port activities, complicates threat prioritization and decision-making for the environmental management of port areas. In order to develop concrete management solutions for port activities impacting coastal dolphin species, it is crucial to pinpoint and compare threats generated by different port activities ²⁹.

Comprehensive empirical data to assess the relative impact of port activities is scarce, therefore expert knowledge can be used to compensate for unavailable data and uncertainty ^{24,30-33}. Through expert elicitation we identified which port activities are perceived to have the highest impact on coastal dolphins, which factors are contributing to these perceptions, and the level of certainty of these perceptions. In order to do this, we conducted an online survey with researchers and environmental managers who have experience with threat and impact assessment for coastal dolphins. Within the survey, a standardized method was applied to identify the vulnerability of coastal dolphin populations to different port activities ²⁴. Additionally, this method was complemented and compared with an impact level assessment and a relative impact assessment ³⁴. The combination of these three methods provides a systematic comprehensive comparative evaluation of how port activities are perceived to affect the coastal dolphin populations.

This comparative impact assessment of different port activities provides insights in the challenges and constraints for both environmental planning, and environmental management of port areas, providing support for managers to optimize the allocation of resources for monitoring, minimizing and mitigating negative impacts generated by port activities. Lastly, the explicit evaluation of knowledge gaps in the impact assessment of port activities provides guidance for researchers working with impact and threat assessment of ports to the marine environment and particularly to coastal dolphin populations.

Material and Methods

Port activities that might affect coastal dolphin populations and their potential direct and indirect impacts were identified through a literature review using Google Scholar, with the following search words: “port activities”, “port construction”, “port operation”, “port impacts” in combination with “coastal dolphins”. Six port related activities were identified and included in the survey and analysis: (1) dredging, (2) port pile driving, (3) increased boat traffic (marine traffic), (4) underwater explosions, (5) environmental accidents and (6) infrastructure development (Table 1).

In order to assess the perceived impacts of these six port activities on coastal dolphins, an expert elicitation was conducted. Experts were identified through a web-based survey of literature (including grey literature) and consisted of managers and scientists with extensive knowledge on marine ecology and potential impacts caused by ports, especially for coastal dolphins. These experts were contacted by email and were provided with information on the aims and objectives of the study. The survey was conducted online using the Google Form platform (Appendix 1). The survey was available for 10 weeks and selected experts received up to four reminders by email. A corresponding email was provided to be used to solve any doubts.

Vulnerability of dolphins to port activities

Experts were first asked to systematically evaluate the impacts of the six port activities on coastal dolphins (as per Halpern et al., 2007), by evaluating the vulnerability of coastal dolphins to each individual port activity. Four vulnerability attributes were scored through a ranking system (Table 3): (1) spatial scale, (2) frequency, (3) functional impact and (4) resilience. These rankings were analysed by a Multiple Criteria Analysis (MCA) to assess the response patterns of the survey participants. MCA is an extension of correspondence analysis (CA) and elucidates the relationship patterns among several categorical dependent variables³⁵, in this case the vulnerability scores of each respondent. The MCA plot demonstrates whether respondents from the same geographic regions gave similar scores during the vulnerability assessment. All analyses and graphics were computed with the packages FactoMinerR³⁶ and facto-extra³⁷ in R.

Afterwards, the ranks for spatial scale and resilience have been rescaled to 0-4, so that all the factors had the same range of values. For each port activity, experts were asked to assign a certainty score, indicating their level of confidence in assessing this activity. Averages and coefficients of variation have been calculated for each vulnerability factor and each port activity.

For each respondent, the four vulnerability scores for each port activity were averaged, to indicate which port activity was most often assigned the highest average vulnerability score. When an expert assigned the highest average vulnerability score to more than one activity, both port activities were considered. Therefore, the number of port activities that were assigned the highest score is greater than the number of respondents.

Impact levels of port activities to coastal dolphins

In the second part of the survey, experts were asked to assign a consequence category to multiple impact levels of each port activity. Impact levels are for example “increased turbidity due to dredging” or “noise pollution due to increased boat traffic” (all impact levels that were scored during the interview are listed in Table 2). Consequence categories ranged from insignificant to catastrophic and were ranked (0-4) in accordance to their potential impact (Table 4, adapted from Fuentes & Cinner, 2010). These rankings were also analysed by a Multiple Criteria Analysis (MCA) in order to see whether respondents from the same geographic regions gave similar scores throughout the impact level assessment.

Afterwards, averages and coefficients of variation have been calculated for each impact level and each port activity. For each respondent, all the impact level scores for each port activity were averaged, to indicate which port activity was most often assigned the highest average impact level score. When an expert assigned the highest average impact level score to more than one activity, both port activities were considered. Therefore, the number of port activities that were assigned the highest score is greater than the number of respondents.

Relative impact of port activities on dolphins

In the last part of the survey, experts were asked to complete a series of pair-wise matrices to determine the relative impact of each port activity (as per Fuentes & Cinner, 2010³⁴). All port activities were compared one to another in order to determine their relative weights (W). Respondents could assign 17 different scores to each comparison of port activities, scores ranged from extremely less impact to extremely more impact (Fig. 1) (as per Pascoe et al. 2009³³). After each pairwise comparison, the respondents were asked to indicate how certain they were about their answers, in order to identify knowledge gaps (as per Halpern et al. 2007 and Selkoe et al. 2008^{24,32}). Weights for the different port activities were calculated from the scores given in the pair-wise matrices using Analytic Hierarchy Process (AHP)³⁸ calculation software available at <http://www.isc.senshu-u.ac.jp/~thc0456/EAHP/AHPweb.html>. AHP is a multi-criteria decision-making method that derives weights of paired comparisons from principal Eigen Vectors³⁸. We averaged the weights for each port activity to obtain a ranking of the relative perceived impact of each port activity (as per Fuentes & Cinner, 2010³⁴). Averages and coefficients of variation have been calculated for each port activity.

Knowledge gaps and consistency

The certainty scores that the respondents provided in the vulnerability assessment give a direct indication of their self-confidence to assess each port activity. A Spearman’s rank correlation test was conducted to investigate the correlation between the average score that the respondent assigned to a port activity, and the average certainty score per port activity.

Additionally, per respondent, the port activities that received the highest score were compared between the three methods: (a) vulnerability assessment, (b) impact level assessment, (c) relative impact assessment through pairwise comparison. In (a) and (b) it is possible that a respondent assigned the same average score to more than one port activity, in the case that more than one port activity received the highest average score, both activities were considered. If a respondent indicated a different port activity as the most impacting one in all three methods, this respondent was assigned a consistency score of D. If a respondent indicated the same activity in two of the three methods, this respondent received a consistency score of C. If the respondent indicated the same activity in (c) and (a) or (b), and another activity in both (a) and (b), this respondent was assigned a consistency score of B. If the respondent indicated the same activity in all three methods, this respondent received a consistency score of A.

Coefficients of variation were used to indicate the level of consensus among experts, classifying CVs lower than 20% as excellent, between 20% and 50% as good, and higher than 50% as a bad level of consensus among respondents.

Results

Experts

We identified and contacted 366 experts, of which 57 (15.6%) experts from 17 different countries responded the survey. Most of the respondents work in research (73.7%), 14.0% in management and 10.5% of the respondents work in both research and management. The researchers work at universities (64.7%), environmental agencies (13.7%), NGO's (11.7%) or a combination of those. The majority of the respondents (67.9%) have over five years of experience, with 17.9% having between five and ten years of experience, 30.4% between ten and twenty years, and 19.7% with more than twenty years of experience working with related issues.

Vulnerability of coastal dolphins to port activities

Researchers from Oceania and Europe have given similar scores during the vulnerability assessment and have less variability in their vulnerability scores than researchers from South America (Fig. 2).

Environmental accidents (average score of 2.79 out of 4, coefficient of variation 31.0%) and infrastructure development (2.78, CV 34.1%) were assigned the highest overall vulnerability scores, followed by increased boat traffic (2.67, CV 30.8%), dredging (2.34, CV 43.4%), underwater explosions (2.29, 47.9%) and port pile driving (1.98, CV 50.9%).

In terms of spatial scale, environmental accidents received the highest scale score (2.47, coefficient of variation 35.4%), followed by underwater explosions (2.04, CV 53.4%), infrastructure development (2.04, CV 44.8%) and increased boat traffic (1.95, CV 40.7%). Dredging (1.56, CV 48.1%) and port

pile driving (1.71, CV 47.8%) are on average perceived to impact coastal dolphins on a smaller spatial scale.

The most prevalent activity was indicated to be increased boat traffic, occurring regularly (average frequency score of 3.65, coefficient of variation 16.8%) , with an excellent level of consensus among the experts. Infrastructure development and dredging were indicated to occur occasionally with frequency scores of 2.98, CV 31.4% and 2.79, CV 31.6%, respectively. Underwater explosions, environmental accidents, and port pile driving are the least occurring activities associated with ports, with frequency scores of 1.49, CV 55.4%; 1.75, CV 49.7%; 1.95, CV 47.0%, respectively.

The functional impact is perceived to be the highest from environmental accidents (3.70, coefficient of variation 18.4%), with an excellent level of consensus among the experts, 23 experts indicated that environmental accidents will impact the entire community. Infrastructure development (3.30, CV 27.5%) received the second highest score for functional impact, and is followed by dredging (3.04, CV 40.3%), underwater explosions (2.88, CV 41.6%), increased boat traffic (2.63, CV 36.4%) and lastly, port pile driving (2.25, 50.7%).

Coastal dolphins and their habitat are perceived to be more resilient for dredging (1.96, coefficient of variation 57.5%), port pile driving (2.04, CV 55.5%) and increased boat traffic (2.43, CV 36.1%); and the least resilient for environmental accidents (3.25, CV 31.0%), infrastructure development (2.81, CV 36.7%) and underwater explosions (2.74, CV 44.6%).

On average, experts indicated to have a higher level of certainty in assessing increased boat traffic (2.58, coefficient of variation 35.1%) and environmental accidents (2.49, CV 44.3%); additionally, the coefficients of variation of the average score of these activities were the lowest of the six activities, indicating that the level of consensus among experts was highest for these two activities (coefficients of variation of 30.8% and 31.0%, respectively). The certainty scores assigned to the four other activities were very similar to each other (Table 5), varying between 1,98 and 2,09.

Infrastructure development and environmental accidents most often received the highest average vulnerability score by all respondents (Fig. 5 and Table 6). Increased boat traffic was assigned the highest score by eleven researchers and two managers; dredging received the highest score by only two researchers and two managers. Only two researchers assigned the highest average vulnerability score to underwater explosions.

Impact levels of port activities for coastal dolphins

The respondents from Oceania assigned similar consequence categories during the impact level assessment. However, none of the other groups (based on geographic location, work area or type of institute) has given similar scorings during the impact level assignment, and all have a high variability (Fig. 3).

The average consequences of different impacts caused by port activities on coastal dolphins were perceived to be highest for environmental accidents (2.29, 49.4%), followed in decreasing order by infrastructure development (2.23, 46.8%), increased boat traffic (2.10, 49.4%), underwater explosions (1.94, 66.2%), dredging (1.89, 59.5%) and port pile driving (1.58, 74.4%).

Environmental accidents received the highest consequence scores for habitat destruction (3.18, coefficient of variation 31.6%), chemical pollution (3.09, CV 36.4%) and increased turbidity (2.07, CV 55.4%) (Table 2 and Figure 4). Considering all port activities, habitat destruction is perceived to be the most impactful consequence of port activities for coastal dolphins (2.53, CV 47.3%), followed by noise pollution (2.26, CV 46.6%) and chemical pollution (2.12, CV 53.8%).

The most impacting consequences of dredging are habitat destruction (2.63, coefficient of variation 45.8%) and chemical pollution (2.11, CV 55.8%). Increased boat traffic is perceived to impact coastal dolphins most significantly by noise pollution (2.53, CV 30.0%) and collisions (2.37, CV 44.2%). Underwater explosions are perceived to impact coastal dolphins most significantly by noise pollution (2.67, CV 46.1%) and habitat destruction (2.44, CV 56.9%). Infrastructure development is perceived to impact coastal dolphins mainly through habitat destruction (2.81, CV 35.3%) (Table 2 and Fig. 4).

Impacts caused by port pile driving received the lowest average score (1.58, CV 74.5%), but also the highest coefficients of variation (five out of six scores have a coefficient of variation higher than 70.5%) which indicates a very low degree of consensus among the experts. Noise pollution (2.28, CV 45.2%) is indicated as the most significant impact of port pile driving.

For each port activity, the impact level with the highest score also had the highest level of consensus among the experts (Table 2). Noise pollution generated by underwater explosions (2.67, coefficient of variation 46.1%) is perceived to have the highest impact on coastal dolphins, followed by increased boat traffic (2.53, CV 30.0%) and port pile driving (2.28, CV 45.2%). Habitat destruction is perceived to be mainly caused by environmental accidents (3.18, CV 31.6%), infrastructure development (2.81, CV 35.3%) and dredging (2.63, CV 45.8%). Alternated bathymetry is perceived to be mainly caused by dredging (1.74, CV 64.0%), followed by infrastructure development (1.72, CV 71.0%) and underwater explosions (1.44, CV 92.9%).

Environmental accidents most often received the highest average score. Underwater explosions were assigned the highest score by five researchers, four managers and two experts who work in both research and management. Infrastructure development was assigned the highest average impact level score by 13 researchers and three managers. While increased boat traffic received the highest average impact score by 10 researchers, only one manager and two experts who work in both research and management assigned the highest average impact score to increased boat traffic. Dredging was assigned the highest average score by three researchers, one manager and one expert who works in

both research and management. Only one researcher assigned the highest average score to port pile driving (Table 6).

Relative impact of each port activity

According to the experts, environmental accidents are ranked as the most impacting activity through pairwise comparison ($W=0.28$, coefficient of variation 56.0%), followed by increased boat traffic ($W=0.19$, CV 74.2%), underwater explosions ($W=0.17$, CV 78.4%) and infrastructure development ($W=0.17$, CV 72.4%) (Fig. 7 and Table 8). In the pairwise comparisons, six researchers indicated infrastructure development as the most impacting port activity, while none of the managers did. Dredging and port pile driving are scored as the lowest impacting activities in the pairwise comparisons ($W=0.10$, CV 83.6% and $W=0.09$, CV 72.9% resp.). In the pairwise comparisons no one indicated port pile driving as the most impacting activity, and only two researchers indicated dredging as the highest impacting activity.

Knowledge gaps and consistency

There is a significant positive correlation between the average certainty scores that the respondents assigned in the vulnerability assessment and the ones they assigned in the pairwise comparisons ($p=2,288 \cdot 10^{-7}$). There is also significant positive correlation between the certainty score that the respondents provided in the vulnerability assessment and the average score of the vulnerability ($p = 5.006 \cdot 10^{-6}$).

The majority of the respondents (87,5 %; $n=50$) indicated the same port activity as the most impactful one in at least two of the three methods. More than one third of the respondents (18 respondents, 32,1 %) indicated the same port activity in all three methods; five (8,9 %) respondents received a consistency rating of B, 26 (46,4 %) of C, and 7 (12,5 %) respondents indicated a different activity in all three methods (rated as D).

Discussion

Ports are affecting coastal dolphin populations in a variety of ways, and the cause-effect pathways of port activities on coastal dolphins are complex, creating a difficult challenge for the environmental management of port areas. This study provides insights in the current state of knowledge, based on expert opinion, of the threats and impacts generated by port activities for coastal dolphin populations and their habitat. Evaluating port impacts per activity allowed an in-depth analysis of the threats and possible impacts, effects and consequences for coastal dolphins, integrating impacts generated by port construction and operation. The comparative approach applied in this study aids the decision-making process to prioritize management actions in order to achieve an effective decrease of threats to coastal dolphins and consequently other components of the marine environment. Moreover, the results allow us to identify needs and priorities for future research on threat and impact assessment of port areas to coastal dolphins. The combination of three different methodologies was useful to compare the relative impacts of port activities to coastal dolphin populations and their habitat, providing a unique approach to the threat and impact evaluation of ports and increasing the reliability and accuracy of the results, allowing an effective evaluation of the stressors and relative impacts that are being generated by port activities.

According to the experts' point of view, coastal dolphin populations are most vulnerable for environmental accidents and infrastructure development, because of a variety of reasons. First of all, both activities are perceived to impact the present coastal dolphin populations through a cascading effect that alters the entire ecosystem on a large spatial scale, because these activities cause direct habitat destruction and secondary environmental degradation due to pollution. Infrastructure development for example causes habitat destruction through land-reclamation; this filling-in of marine habitats to produce land eliminates dolphin habitats^{28,39,40}. Additionally, the dolphins' habitat is being degraded by infrastructure development through sewage effluents that introduce vast quantities of bacteria, protozoa and viruses in the environment, to which coastal dolphins are being exposed directly, and indirectly through the ingestion of contaminated prey⁴⁰.

Moreover, coastal dolphins and their habitat are also perceived to be less resilient to both infrastructure development and environmental accidents, which implies that dolphins are perceived to have a low resistance, limited reversibility capacity, and long recovery time after infrastructure development and environmental accidents. Experts expect that coastal dolphins have a low resilience to these activities, because both environmental accidents and infrastructure development are perceived to cause severe habitat destruction and chemical pollution, which strongly impact coastal dolphin populations. During the aftermath of large environmental accidents, coastal dolphins have indeed demonstrated a slow health recovery, with increased morbidity and mortality, particularly because of pulmonary abnormalities and impaired stress response⁴¹. Furthermore, affected dolphin populations present high reproductive failure rates⁴².

Risk management frameworks often implement information on the severity of the consequences of port activities with the frequency, and thus likelihood of them occurring, in risk matrices⁴³⁻⁴⁵. This approach combines the likelihood with the consequence level scores resulting in the proposed risk matrix (Fig. 8), which can be used directly as a prioritization tool, to determine the acceptability of the threats generated by that port activity, and the urgency of management strategies to avoid or reduce the impacts^{34,46}. In the present study, the combination of severity and likelihood provides a slightly different panorama of the prioritization of port activities. Infrastructure development and environmental accidents still emerge as priorities; however, dredging and increased boat traffic also pop up as high-risk activities. Dredging and increased boat traffic are both perceived to impact coastal dolphin populations and their environment on a relatively small spatial scale; however, there is a high level of consensus among the experts that their functional impact on the ecosystem is high. Dredging is perceived to impact coastal dolphins mainly through habitat destruction, which might cause avoidance of the area¹⁵, and chemical pollution. Dredging causes pollution through the redistribution of contaminants, such as heavy metals and organochlorides, that are settled on the seabed and are stirred up into the water column. This contaminant release by resuspension increases the bioaccumulation of contaminants due to the consumption of prey in the vicinity of the work area^{15,47}.

Increased boat traffic mainly affects coastal dolphins through noise pollution and increased collision risks. High levels of marine traffic in areas used by coastal dolphins, increases the chance of collisions, which might result in injuries and even death^{25,26,47,48}. Noise pollution emerged as one of the most impactful effects of port activities, mainly noise caused by underwater explosions and increased boat traffic. Acoustic pollution is one of the most extensively investigated impacts of anthropogenic activities to coastal dolphins, and generates a wide array of consequences, such as physiological responses (temporary or permanent hearing threshold shifts, reducing the efficiency of echolocation), behavioural responses (avoidance, changes in surfacing, breathing and diving patterns, changes in group composition, abandonment of important activities or locations), acoustic responses (changes in type or timing of vocalizations), and lastly the masking of biologically significant sounds can affect dolphins' health and impair their ability to detect certain prey and to communicate⁴⁹⁻⁵³.

This wide variety of different anthropogenic activities generated by ports, impact coastal dolphins directly and indirectly through complex cause-effect pathways. The associations among these activities and their effects and consequences for coastal dolphins are convoluted, particularly because many of the threats and stressors are generated by multiple sources. Cumulative and synergistic threat and impact assessment builds on the comparison of impacts and effects and thus the prioritization of management actions⁵⁴. The management strategies and actions that can avoid, minimize and mitigate the impacts of the assessed port activities are extensive, but highly complex and challenging. Therefore, adaptive management is crucial to elucidate these management challenges, so that management strategies that are being trialled around the world can be communicated and management

plans can continuously be improved (Fazey 2005). In order to minimize the impacts and consequences of environmental accidents and infrastructure development, which are the port activities that are perceived as the most threatening, the implementation of long-term, continuous and precautionary management actions is necessary. Possible mitigation measures to decrease the impacts of infrastructure development are for example bubble curtains/jackets, exclusion zones, ramping up of piling hammers, acoustic decoupling of noisy equipment, vessel speed limits, no-dumping policies, silt curtains and a long-term ecological cetacean monitoring and audit program, to verify the accuracy of prediction of the EIA, monitor the effectiveness of mitigation measures, and recommend action plans in response to unpredicted impacts ^{47,55}.

In order to reduce the risk of environmental accidents it is crucial to implement a series of precautionary security measures, minimizing the risks of technical and mechanical failures, and the risk of human errors. This approach should be based on risk avoidance and anticipation, identifying and evaluating foreseeable risks. Additionally, the human element involves enhanced training programmes and qualification of the operators, in combination with the provision of a well-engineered working environment in order to minimize both the operational failures and ecological and socioenvironmental impacts. This people-focused approach should also improve stakeholder involvement through communication and engagement with local communities, investing in a socio-environmental risk management initiative that includes risk perception, risk communication and environmental education to create community awareness on emergency responses ⁵⁶. When an environmental accident occurs, it is crucial to take coastal dolphin populations into account during response activities and damage assessments. Even though previous studies have suggested that dolphins could be able to detect and avoid oiled waters ⁵⁷, more recent studies documented the direct exposure of cetaceans to petroleum, and the persistence of the oil on their skin ⁵⁸. Furthermore, it has been shown that dolphins might move away immediately after an environmental accident, yet dolphins with a strong site fidelity will return and continue to use the area, despite the pollution ^{59,60}. This highlights the importance of studies on habitat-use and residency patterns, which will provide crucial guidance for restoration activities if an environmental accident occurs ⁵⁹. Long-term monitoring of impacted dolphin populations is critical to fully understand both the potential and timeline of individual and population recovery from environmental accidents, in order to obtain insights into the long-lasting effects of environmental accidents on marine mammals and ecosystem health ⁴¹. Lastly, many of the impacts and consequences generated by port activities might potentially be avoided, minimized and mitigated through technological development. Improving the connection between research, industry and entrepreneurs, might provide solutions by developing techniques and technological innovations that are environmentally less impacting ⁶¹.

Management strategies to reduce port impacts should aim to provide an integrated and holistic prevention program, incorporating spatial, temporal and practical limitations with technical

innovations and precautionary measures. The potential for effective implementation of environmental management plans in port areas largely depends on the local socio-economic conditions. Therefore, a relationship between the geographical origin of the experts and their perspectives on port impacts might be expected. The fact that respondents from Oceania assigned similar scores throughout the survey, might be because Australia has an extensive history of impact and threat assessments of port areas, and a comprehensive set of environmental port management plans^{13,62}.

The best management strategies may vary geographically and according to the magnitude of specific port activities that might occur, however, the high heterogeneity of our carefully selected expert group allows us to identify general patterns in perceptions that are not restricted by geographical location, nor species. There often tends to be a disconnect between managers and researchers when ranking threats and impacts^{34,63,64}, but within our expert group researchers and managers demonstrated similar perceptions about which port activities are most impacting for coastal dolphin populations and their habitats. This might be due to either the size of the expert group, because some researchers were also managers, or because of the wide variety of geographical and institutional backgrounds. The high geographical and institutional heterogeneity within the expert group might mask some of the differences that could emerge if the expert group was more homogenous. When facing constraints, managers should focus their resources and efforts on management actions that target the port activities that are perceived to have the highest impact on coastal dolphins, or aim for damage reduction, by targeting directly the impacts generated by multiple sources that are perceived to have the worst consequences for coastal dolphins and their environment. This means that in order to decrease the consequences of dredging, environmental accidents and infrastructure development for coastal dolphins, managers should aim to implement actions that reduce habitat destruction and chemical pollution. While for port pile driving, increased boat traffic and underwater explosions, management actions that avoid noise pollution should be prioritized.

Researchers should focus their attention on filling the identified knowledge gaps of the impacts, effects and consequences of port activities, and the cumulative and synergistic interactions that may occur in port areas. This study explicitly assessed the uncertainties and consensus levels of the respondents in order to detect knowledge gaps and research needs. The comparison of the different port activities indicates that major knowledge gaps remain, especially regarding the impacts caused by port pile driving. Port pile driving received the lowest scores in both the vulnerability assessment and the impact level assessment, and experts were consistently uncertain in their evaluation of port pile driving, despite the significant acoustic impacts of port pile driving to coastal dolphins^{47,65-67}. Furthermore, there was also a very low level of consensus and thus a high level of disagreement among the respondents for the scorings of port pile driving. The on average low degree of impact attributed to port pile driving may be a reflection of the experts' high uncertainty on the impacts that port pile driving has on coastal dolphins, since respondents might be inclined to assign a lower impact

score to those port activities with which they are not familiar. Respondents might assess the port activities about which they have more knowledge as more impactful. This hypothesis can be supported by the fact that there is a significant positive correlation between the certainty score that the respondents provided in the vulnerability assessment and the average score of the vulnerability. Accordingly, the more knowledge experts have about a certain port activity, the more vulnerable they think that coastal dolphins are for this port activity.

The results provide valuable insights into how ports are threatening coastal dolphin populations, however, information based on expert elicitation should always be interpreted with care. All the results are a reflection of the respondents' knowledge and might therefore be influenced by a variety of factors. Particularly the results for which there was a high *coefficient of variation* and thus a high level of disagreement among the respondents, should be interpreted with caution. On the contrary, when the consensus level is high, the reliability of the results increases. For example, during the impact level assessment, the impact level with the highest score also had the highest level of consensus among the experts for all port activities, which increases the reliability of the results. Furthermore, results obtained through expert elicitation should be integrated and complemented with knowledge gathered through other scientific methods, in order to verify and validate the results. Therefore, it is important to compare results obtained through expert elicitation with published data, in order to validate the results and guide and reinforce the directions and suggestions that emerged through expert elicitation.

In conclusion, the methodology provided unique perspectives on which port activities are perceived to have the highest impact on coastal dolphins, and why. These impact insights for coastal dolphins can easily be extrapolated to understand ecosystem health and functioning facing port activities, since coastal dolphins serve as optimal environmental sentinels. Environmental management of port areas should be focused on continuous, preventative, precautionary measures in order to reduce the chance of environmental accidents, minimizing and mitigating the impacts of infrastructure development for coastal dolphin populations, and consequently for other components of the marine ecosystem. Research efforts should be focused on those activities for which there is a high level of uncertainty and disagreement among the experts, such as for example port pile driving. Furthermore, port activities that are perceived as highly impacting, and stressors generated by multiple sources should be targets for future scientific research, aiming to avoid, minimize and mitigate consequences for the marine environment. The comparative impact assessment that was conducted in this study enables the prioritization of management actions, providing support for decision-making within the environmental management of port areas. Finally, this study provides a great starting point to support cumulative impact assessments that consider the synergistic effects of the different activities that are being generated by the port.

Future recommendations

Recommendations for scientific research

In a nutshell, future scientific research should aim to:

- Produce relevant information for management and policy makers regarding environmental threat and impact assessments of port areas ⁶⁸.
- Integrate stakeholders, and minimize the knowledge gap between researchers, managers and policy makers ⁶³ by delivering scientific results in a “management friendly” way, in order to facilitate the implementation of scientific knowledge in environmental management practice, and even offer practical management strategies ⁶³.
- Consider economic, political, and social issues, in order to suggest both scientifically optimal strategies, and sub-optimal alternatives that might be more feasible ³⁴.
- Focus on those port activities for which there is a high level of disagreement among the respondents, or for which there is a high level of uncertainty, in order to elucidate the source-impact pathways and consequences of these activities for coastal dolphins. In this study, experts had the highest level of uncertainty and disagreement about the impacts and consequences of port pile driving.
- Assess how the consequences of port activities that are perceived to be highly impacting can effectively avoided, reduced, and mitigated. For example, through technological innovations and improved stakeholder involvement.
- Elucidate the complex source-impact pathways of the multiple threat sources generated by anthropogenic activities in port areas.
- Direct research efforts to the cumulative impact assessment of port areas, taking into account the synergistic impacts of simultaneous port activities ⁶⁹.

Recommendations for environmental management of port areas

- As management options are being trialled around the world, information about their success should be spread, in order to develop shared knowledge and ultimately guidelines for environmental management (Fuentes 2010c). This sharing of experience is critical for adaptive management, where managers learn as they go and can adapt the management strategies as they learn (Fazey 2005)
- Management strategies to reduce port impacts should aim to provide an integrated and holistic prevention program, incorporating spatial, temporal and practical limitations with technical innovations and precautionary measures.
- On one hand, managers should focus their efforts and resources on damage reduction actions, focussing on minimizing and mitigating the consequences of the impacts caused by multiple sources of anthropogenic activities in port areas. Particularly to avoid habitat destruction, chemical pollution and noise pollution, which are perceived as the most catastrophic consequences of the anthropogenic activities generated by ports.
- On the other hand, environmental managers should aim to minimize the impacts and consequences of environmental accidents and infrastructure development, which are the port activities that are perceived as the most threatening, through the implementation of long-term, continuous and precautionary management actions.
- In order to decrease the consequences of dredging, environmental accidents and infrastructure development for coastal dolphins, managers should aim to implement actions and damage reduction techniques that reduce habitat destruction and chemical pollution.
- When facing threats generated by port pile driving, increased boat traffic and underwater explosions, management actions should prioritize noise reduction.
- The environmental management approaches in port areas should be based on risk avoidance and anticipation, identifying and evaluating foreseeable risks for the marine environment.
- To reduce the risk of environmental accidents, it is crucial to implement a series of precautionary security measures, minimizing the risks of technical and mechanical failures, and also minimizing the risk of human errors. The human element involves enhanced training programmes and qualification of the operators, in combination with the provision of a well-engineered working environment in order to minimize both the operational failures and ecological and socioenvironmental impacts.
- A people-focused approach should also improve stakeholder involvement through communication and engagement with local communities, investing in a socio environmental risk management initiative that includes risk perception, risk communication and environmental education to create community awareness on emergency responses (Poffo 2008)

- Possible mitigation measures are for example bubble curtains/jackets, exclusion zones, ramping up of piling hammers, acoustic decoupling of noisy equipment, vessel speed limits, no-dumping policies, silt curtains and long-term cetacean monitoring (Jefferson 2008, Gupta 2005).

Figures and tables

Table 1. Definitions of the six port activities based on the literature review about ports and potential impacts for coastal dolphins. These definitions were available for the respondents during the entire online survey that aimed to assess the impacts of port activities to coastal dolphins.

Port activity	Definition
Dredging	During dredging operations sediment is removed and displaced to disposal sites, this causes suspension of sediments and intense traffic of dredging equipment in both the dredged areas and the disposal sites. Dredging is commonly used during both port construction (deepening of the channel, land reclamation, etc.) and operation (maintenance dredging).
Port pile driving	High-energy impact hammers are used to drill/hammer and ground port piles, which are for example used for the construction of platforms in the port. The installation of these port piles produces high sound levels in the surrounding water and air.
Infrastructure development	This not only includes port infrastructure development, but also increased urbanization, which is a side-effect and will alter the marginal areas surrounding the port. This can cause habitat destruction, alteration of the substrate, coastal erosion, loss of flood plains, sewage discharge, increased marine debris, increased air and water contamination, altered storm water run-off, altered agricultural effluents which alter nutrient cycling, and pollution from cargo-handling equipment, on-road trucks, locomotives, etc.
Explosions	In- and nearshore explosions are used during the port construction and operation. Underwater blasting is for example used to create deeper areas around the port in order to optimize navigation possibilities.
Environmental accidents	Different types of environmental accidents can occur in association with ports, including oil spills, chemical substance leaks, shipping incidents, groundings etc. Small accidents are also considered, since small regular spills might have large cumulative effects.
Increased boat traffic	The construction and operation of a port generates intense traffic of several vessels, for example bulk carriers and containerships, but also support boats such as pilotage boats, maintenance ships during the construction of the port.



Fig. 1. Format of a pair-wise comparison matrix given to respondents to complete during the online survey to evaluate the impacts of port activities to coastal dolphins.

Table 3. Description of the vulnerability categories and their ranking system that were provided to the respondents during the online survey to assess the impacts of port activities to coastal dolphins.

Scale	Average scale at which a port activity affects coastal dolphin populations. Scale includes both direct and indirect impacts and is expressed in square kilometres. 0 No impact 1 < 1 km ² 2 1-10 km ² 3 10-100 km ² 4 100-1000 km ² 5 1000 – 10 000 km ² 6 >10 000 km ²
Frequency	How often discrete port activities occur in areas where coastal dolphin populations are present. For port activities that occur as discrete events, frequency represents how often new events occur, not the duration of a single event. 0 Never occurs 1 Rare 2 Occasional 3 Annual or regular 4 Persistent
Functional impact	The extent of influence within an area that is used by coastal dolphins. Some port activities may affect only a few species, whereas others affect the entire ecosystem. 0 No impact 1 Species level: One or more species in a single of different trophic levels 2 Single trophic level: Multiple species affected; entire trophic level changes 3 Multiple trophic levels: Multiple species affected, multiple trophic levels change 4 Entire community: Cascading effect that alters the entire ecosystem
Resilience	The average tendency of a species, trophic level, or community to resist changing its natural state in response to a port activity. The ranking scheme refers to the resistance, reversibility and recovery of the ecosystem components that react to the hazard (i.e. the functional level that was identified in the previous step) <ul style="list-style-type: none"> • Resistance is the ability of the effected ecosystem components to remain unchanged • Reversibility is the ability of the effected ecosystem component to recover their ecological functions • Recovery time is the average time required for the affected ecosystem components to recover their ecological functions. For persistent hazards, we consider the recovery time following removal of the threat 0 Not applicable 1 High 2 Medium 3 Low
Certainty	A qualitative measure of certainty that indicates the depth of knowledge used to determine vulnerability. 0 Not applicable 1 Low certainty: Very little or no empirical work exists, or the expert has limited personal experience 2 Moderate certainty: Some empirical work exists, or expert has some personal experience 3 High certainty: Body of empirical work exists, or the expert has direct personal experience 4 Very certain: Extensive empirical work exists or the expert has extensive personal experience

Table 4. Ranking system for consequence levels. During the online survey to assess the impacts of port activities to coastal dolphins, experts were asked to assign these consequence categories to several impact levels (described in Table 2).

Score	Consequence level	Description
0	Insignificant	No impact on the overall condition of the species or population
1	Minor	Impact is present but not to the extent that it would impair the overall condition of the coastal dolphin population

2	Moderate	Impact is present either at a local or population level. Recovery period within one generation is likely
3	Major	Impact is significant at either a local or population level to the coastal dolphin populations
4	Catastrophic	Impact is clearly affecting the coastal dolphin population over a wide area, or the impact is irreversible over a small area (nursing areas), or a sensitive part of the ecosystem is irretrievably compromised

Fig. 2. Multiple Criteria Analysis (MCA) plots for qualitative variables that were obtained through an online survey to assess the impacts of port activities to coastal dolphins. Points represent answers from respondents throughout the **vulnerability assessment**, and clusters are generated for answers of the same category based on geographic region. Confidence ellipses of the mean were added.

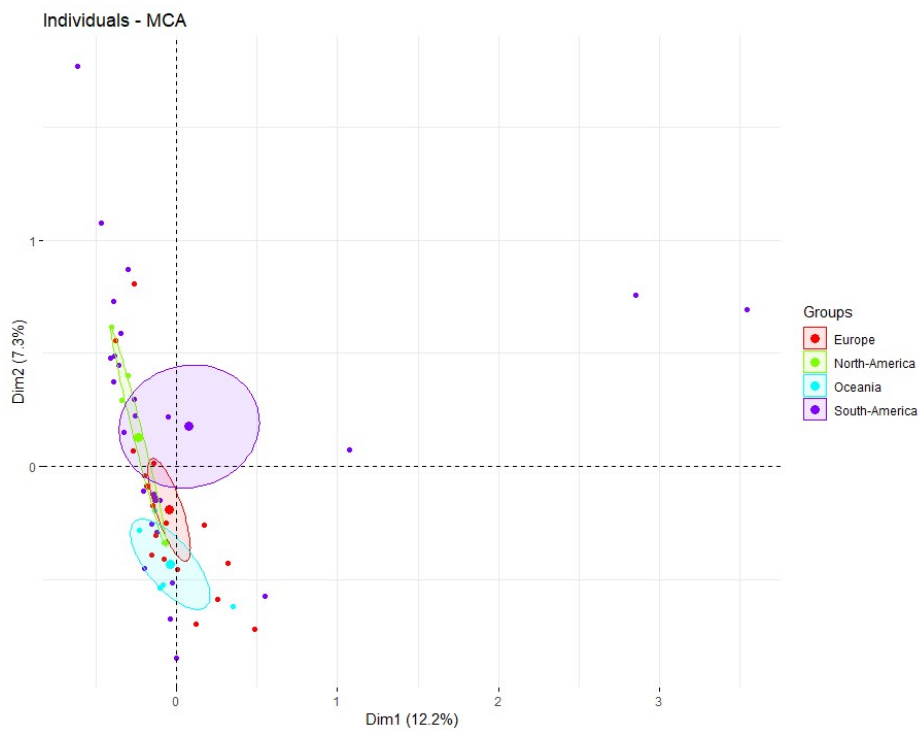


Table 5. Average weights for each of the vulnerability categories that were assessed through an online survey to assess the impacts of port activities to coastal dolphins. Scores with excellent consensus levels are underlined, scores with high consensus levels are italic. Per vulnerability category the highest average score is bold. Shading is based on the average value (lower than 2 in green, between 2 and 2.5 in yellow, between 2.5 and 3 in orange, and higher than 3 in red).

Dredging	Port pile driving	Increased boat traffic	Explosions	Environmental	Infrastructure
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				accidents		development
Scale	1,56	1,71	1,95	2,04	2,47	2,04
Frequency	2,79	1,95	3,65	1,49	1,75	2,98
Functional impact	3,04	2,25	2,63	2,88	3,70	3,30
Resilience	1,96	2,04	2,43	2,74	3,25	2,81
Average	2,34	1,98	2,67	2,29	2,79	2,78
Certainty	2,02	1,98	2,58	2,09	2,49	2,00

Fig. 3. Multiple Criteria Analysis (MCA) plots for qualitative variables, that were obtained through an online survey to assess the impacts of port activities to coastal dolphins. Points represent answers from respondents throughout the **impact level assessment**, and clusters are generated for answers of the same category based on geographic region. Confidence ellipses of the mean were added.

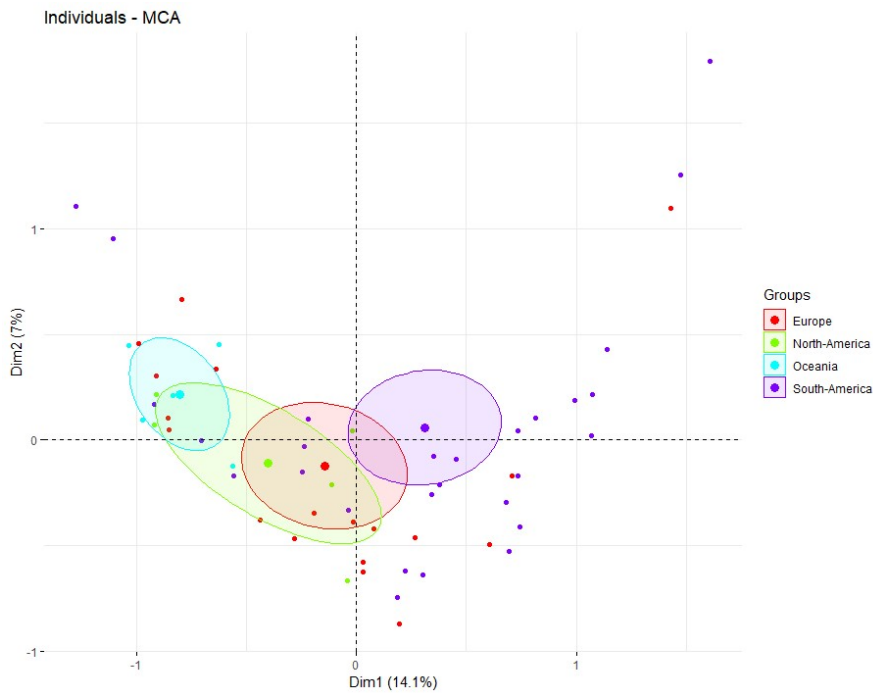


Table 2. Average scores of the impact levels assigned by experts during the online survey to assess the impacts of port activities to coastal dolphins, based on the ranking system described in Table 4. Shading is based on the average score (higher than 2.5, red; between 2 and 2.5, orange; between 1.5 and 2, yellow; lower than 1.5, green). Scores with high consensus levels are italic

Dredging
 Port pile driving
 Increased boat
 Explosions
 Environmental
 Infrastructure

		traffic	accidents	development			
Increased turbidity	1,6	1,32	1,49	1,53	2,07	1,89	
Noise pollution	1,9	2,2	2,5	2,6	1,91	2,25	
Chemical pollution	2,1	1,54	1,89	1,61	3,0	2,47	
Collisions	1,2	1,14	2,3	7	NA	NA	
Habitat destruction	2,6	3	1,93	2,21	2,44	3,1	2,8
Alternated bathymetry	1,7	4	1,28	NA	1,44	1,23	1,72

Fig. 4. Spiderplots with the average scores of each of the assessed impact levels for the six port activities that were evaluated through an online survey about the impacts of port activities to coastal dolphins: (a) dredging, (b) port pile driving, (c) boat traffic, (d) explosions, (e) environmental accidents, (f) infrastructure development.

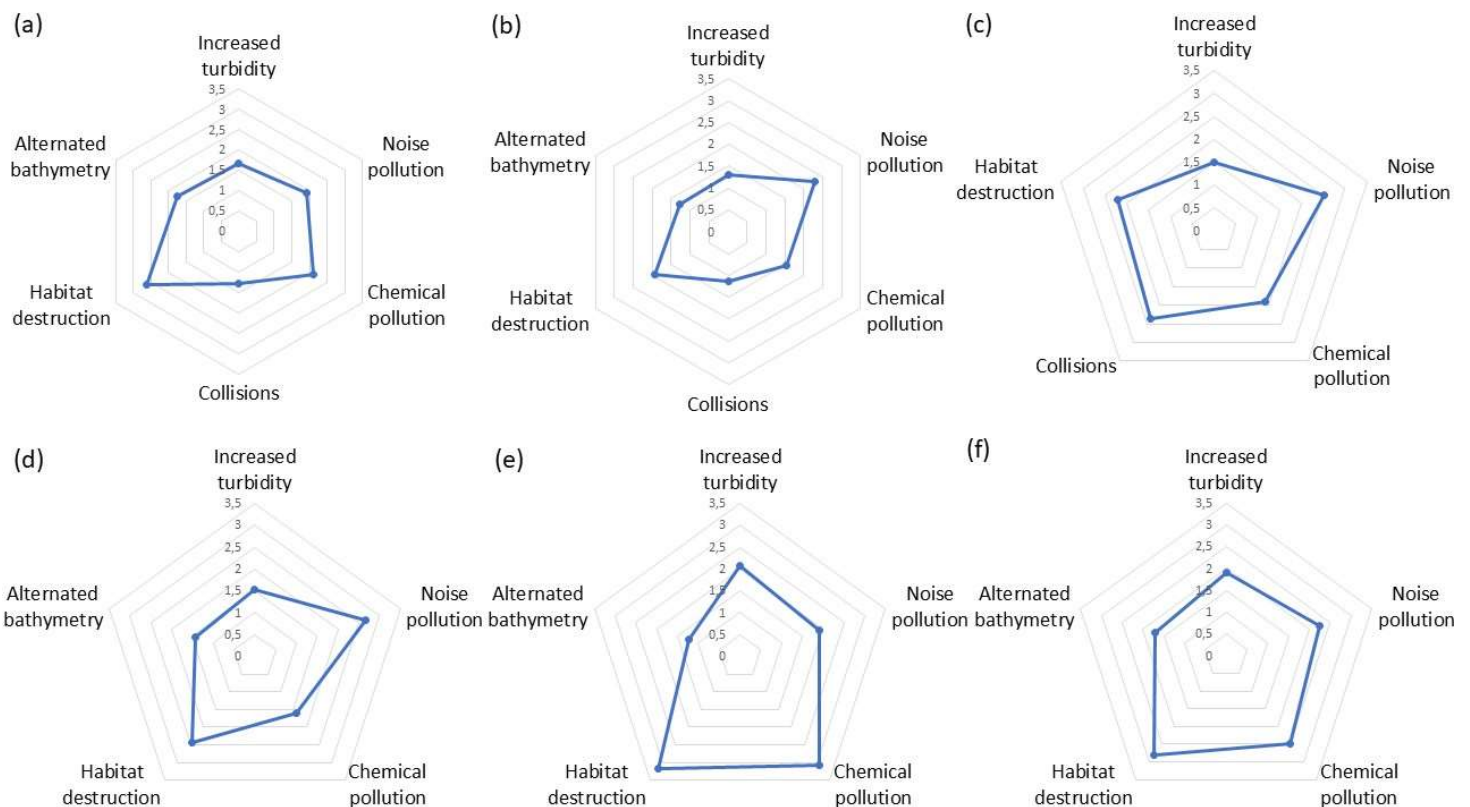


Fig. 5. Port activities which were assigned the highest scores in the three parts of the online survey to assess the impacts of port activities to coastal dolphins, by respondents working in research,

management, or both. In the first two parts of the survey (vulnerability assessment and impact level scoring), it was possible that a respondent assigned the same average score to more than one port activity. If more than one port activity received the highest average score, all activities were added to n, therefore, n might be larger than the number of respondents.

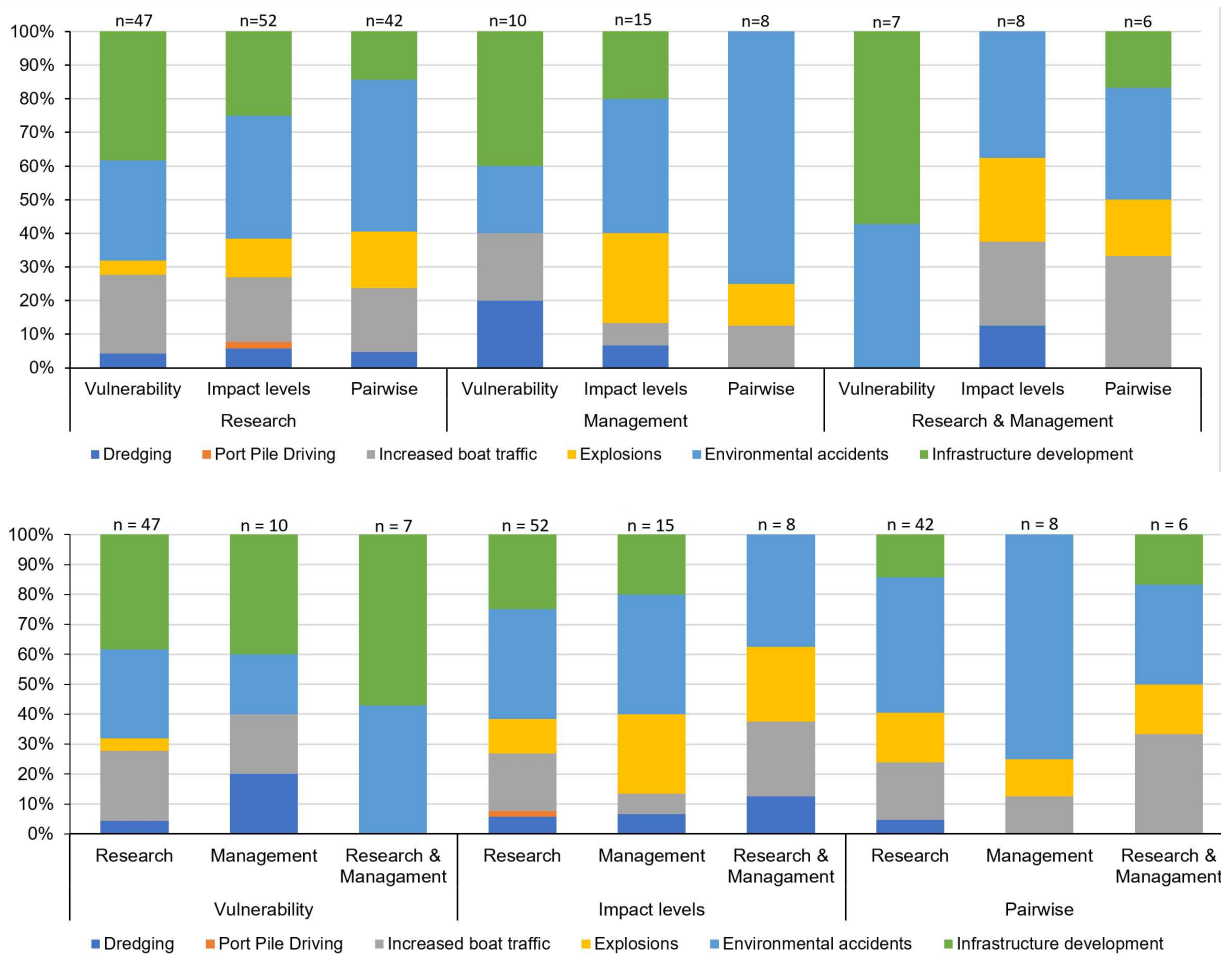


Table 6. Port activities which were assigned the highest scores in the three parts of the survey to assess the impacts of port activities to coastal dolphins, by respondents working in research, management, or both. In the first two parts of the survey (vulnerability assessment and impact level scoring), it was possible that a respondent assigned the same average score to more than one port activity. If more than one port activity received the highest average score, all activities were counted.

		Dredging	Port Pile Driving	Increased boat traffic	Explosions	Environmental accidents	Infrastructure development
Research	Vulnerability	2	0	11	2	14	18
	Impact levels	3	1	10	6	19	13
	Pairwise	2	0	8	7	19	6
Management	Vulnerability	2	0	2	0	2	4
	Impact levels	1	0	1	4	6	3
	Pairwise	0	0	1	1	6	0
Research & Management	Vulnerability	0	0	0	0	3	4
	Impact levels	1	0	2	2	3	0
	Pairwise	0	0	2	1	2	1

Fig. 6. Port activities which were assigned the highest scores in the three parts of the survey to assess the impacts of port activities to coastal dolphins, by years of experience of the respondents. In the first two parts of the survey (vulnerability assessment and impact level scoring), it was possible that a respondent assigned the same average score to more than one port activity. If more than one port activity received the highest average score, all activities were added to n, therefore, n might be larger than the number of respondents.

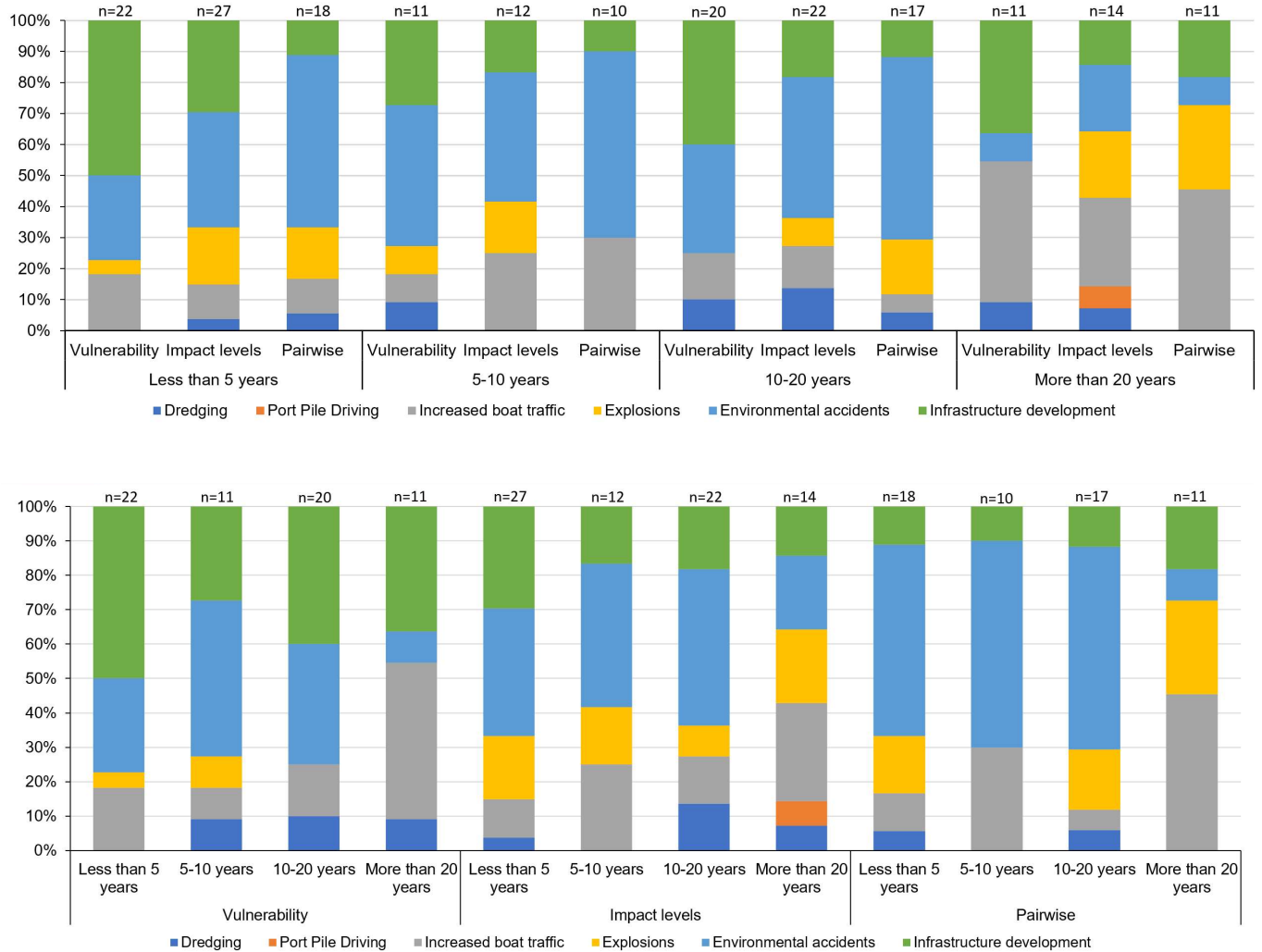


Table 7. Port activities which were assigned the highest scores in the three parts of the survey to assess the impacts of port activities to coastal dolphins, by years of experience of the respondents. In the first two parts of the survey (vulnerability assessment and impact level scoring), it was possible that a respondent assigned the same average score to more than one port activity. If more than one port activity received the highest average score, all activities were counted.

		Dredging	Port Pile Driving	Increased boat traffic	Explosions	Environmental accidents	Infrastructure development
Less than 5 years	Vulnerability	0	0	4	1	6	11
	Impact levels	1	0	3	5	10	8
	Pairwise	1	0	2	3	10	2
5-10 years	Vulnerability	1	0	1	1	5	3
	Impact levels	0	0	3	2	5	2

	Pairwise	0	0	3	0	6	1
10-20 years	Vulnerability	2	0	3	0	7	8
	Impact levels	3	0	3	2	10	4
	Pairwise	1	0	1	3	10	2
More than 20 years	Vulnerability	1	0	5	0	1	4
	Impact levels	1	1	4	3	3	2
	Pairwise	0	0	5	3	1	2

Fig. 7. Average vulnerability scores and the average weights of the pairwise comparisons for each port activity (Dredging (D), Port pile driving (P), Increased Boat Traffic (B), Environmental Accidents (A), Explosions (E), Infrastructure Development (I)). These scorings were obtained through an online survey to assess the impacts of port activities to coastal dolphins.

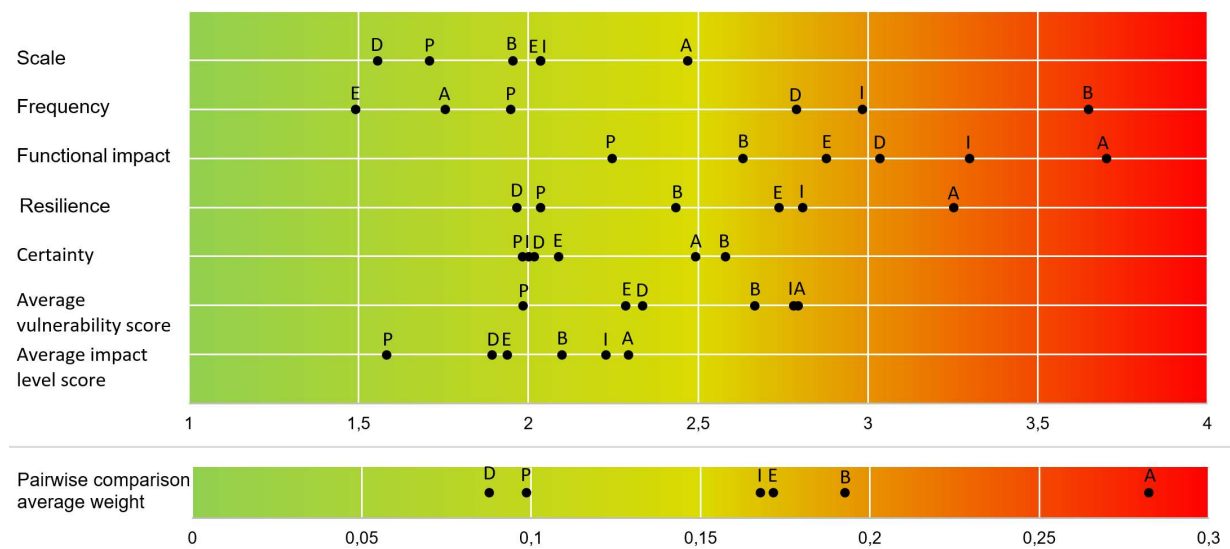


Table 8. Relative weights assigned to each port activity (possible weight range is from 0 to 1) during an online survey to assess the impacts of port activities to coastal dolphins.

Port activity	Average weights	Coefficients of Variation
Dredging	0,10	82.6%
Port pile driving	0,09	72.9%
Increased boat traffic	0,19	74.1%
Explosions	0,17	78.4%
Environmental accidents	0,28	56.0%
Infrastructure development	0,17	72.4%

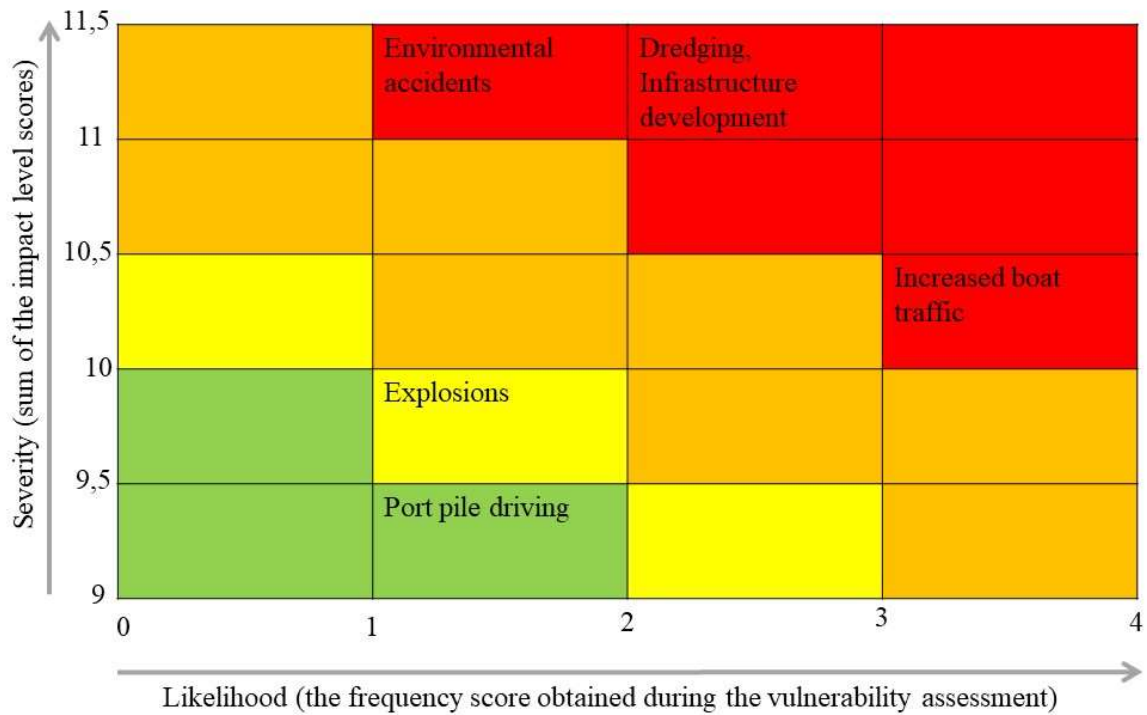


Fig. 8. Risk matrix of the six assessed port activities that were assessed during an online survey on the impacts of port activities to coastal dolphins. The severity score is the sum of the impact level scores which were assigned during the impact level assessment. The likelihood is the frequency score that was obtained during the vulnerability assessment. Cells coloured in red represent extremely high risk for coastal dolphins and their environment, orange represents high risk, yellow represents average risks, and green represents low risks.

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Appendix I: Survey that was available online to the respondents for 10 weeks.

Survey – Port activities and their impact on coastal dolphin populations

This survey assesses the relative impact of port activities on coastal dolphin populations. You are part of a small, select group of experts invited to take part in an expert elicitation study to identify which port activities have the highest impact on coastal dolphin populations and should be prioritized in the management to optimize the species and habitat conservation.

Most impact and risk assessments that study the direct and indirect impacts of port activities on dolphins focus on one particular activity, area or species. However, in order to effectively manage port activities and optimize the protection and conservation of coastal dolphins, it is important to obtain insights into the relative impacts of different activities. Therefore, we are collecting opinions from multiple experts globally in both research and managerial positions on their views about key port activities and how they are affecting dolphin populations. The results from this study will result in a peer-reviewed publication on the relative impacts of port activities on dolphins.

The survey consists of three main parts: (i) First we will ask you to score six port activities in four vulnerability categories; (ii) Second, you will be asked to assign a consequence category to several impact levels; (iii) Third, we will ask you to complete a series of pairwise comparisons between the six port activities to determine their relative impacts. This survey should not take more than 15 minutes.

Your responses and contact details will be strictly confidential, survey responses will not be identifiable to individuals in any way in any publication. Taking part in this study is completely voluntary and you can withdraw at any time without explanation or prejudice.

The survey will be open until the 1st of January 2017, and we will send subsequent reminders until the survey is closed. This survey is being conducted by Prof. Dr. Camila Domit and Tara Van Belleghem, from the Ecology and Conservation Laboratory (LEC) - Federal University of Paraná.

If you have any questions about the study, please contact: vanbelleghemtara@gmail.com

You consent to participate in this study

- I CONSENT to participate in this survey (continue to the survey)
- I DO NOT consent to participate in this survey (exit survey)

Personal information

Please provide the following personal information. All information concerning individuals is strictly confidential, and will not be published or released. Your participation is entirely voluntary.

- Country where most of your work is undertaken:

- What is your main work area?
 - Management
 - Industry
 - Research
- Where do you conduct your research?
 - University
 - NGO
 - Agency
- Please describe your experience with port areas/activities and/or coastal dolphin populations:

- How many years have you worked with coastal dolphins and/or port areas?
 - Less than 5 years
 - 5-10 years
 - 10-20 years
 - More than 20 years

Impact assessment

We identified six activities associated with port development, as described below. To evaluate your perception of the vulnerability of coastal dolphin populations to each activity, we ask you to consider the spatial scale, frequency, functional impact and the resilience and recovery time of dolphin populations to each activity.

The **6 port activities** are:

- 1. Dredging**

During dredging operations sediment is removed and displaced to disposal sites, this causes suspension of sediments and intense traffic of dredging equipment in both the dredged areas and the disposal sites. Dredging is commonly used during both port construction (deepening of the channel, land reclamation, etc.) and operation (maintenance dredging).
- 2. Port pile driving**

High-energy impact hammers are used to drill/hammer and ground port piles, which are for example used for the construction of platforms in the port. The installation of these port piles produces high sound levels in the surrounding water and air.
- 3. Increased boat traffic**

The construction and operation of a port generates intense traffic of several vessels, for example bulk carriers and container ships, but also support boats such as pilotage boats, maintenance ships during the construction of the port.
- 4. Infrastructure development**

This not only includes port infrastructure development, but also increased urbanization, which is a side-effect and will alter the marginal areas surrounding the port. This can cause

habitat destruction, alteration of the substrate, coastal erosion, loss of flood plains, sewage discharge, increased marine debris, increased air and water contamination, altered storm water run-off, altered agricultural effluents which alter nutrient cycling, and pollution from cargo-handling equipment, on-road trucks, locomotives, etc.

5. Explosions

In- and nearshore explosions are used during the port construction and operation. Underwater blasting is for example used to create deeper areas around the port in order to optimize navigation possibilities.

6. Environmental accidents

Different types of environmental accidents can occur in association with ports, including oil spills, chemical substance leaks, shipping incidents, groundings etc. Small accidents are also considered, since small regular spills might have large cumulative effects.

In literature, several consequences of these activities have been described for coastal dolphin populations, for example, changes in behaviour (abandoning of the area, changed nursing and foraging behaviour, ...), but also impaired health (due to acoustic trauma, immunological and reproductive problems, injuries and mortality, ...)

Please consider each of the **vulnerability categories** below for the activities described:

Geographical scale is defined as the average scale at which a port activity affects coastal dolphin populations. Scale includes both direct and indirect impacts. Scale is expressed in square kilometres.

- No impact
- < 1 km
- 1-10 km
- 10-100 km
- 100-1000 km
- 1000 - 10 000 km
- > 10 000 km

	No impact	< 1	1-10	10-100	100-1000	1000-10 000	>10 000
Dredging							
Port pile driving							
Increased boat traffic							
Infrastructure development							
Explosions							
Environmental accidents							

Frequency describes how often discrete port activities occur in areas where coastal dolphin populations are present. For port activities that occur as discrete events, frequency represents how often new events occur, not the duration of a single event.

- **Never occurs**
- **Rare:** Infrequent enough to affect long-term dynamics of a given population or location
- **Occasional:** Frequent but irregular in nature
- **Annual or regular:** Frequent and often seasonal or periodic in nature

- **Persistent:** More or less constant year-round, lasting through multiple years or decades

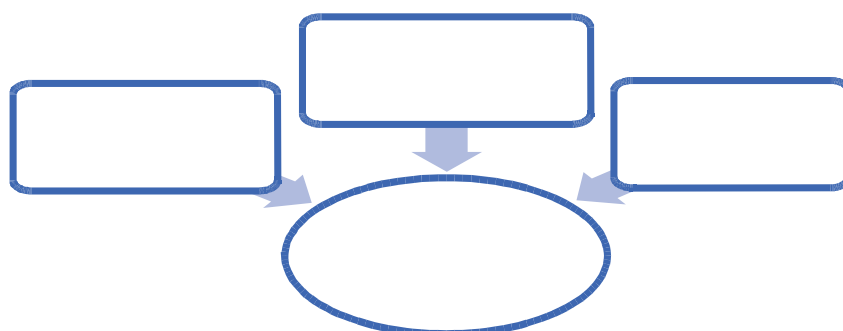
	Never occurs	Rare	Occasional	Annual or regular	Persistent
Dredging					
Port pile driving					
Increased boat traffic					
Infrastructure development					
Explosions					
Environmental accidents					

Functional impact defines the extent of influence within an area that is used by coastal dolphins. Some port activities may affect only a few species within this area, whereas others affect the entire ecosystem.

- **No impact**
- **Species level:** One or more species in a single or different trophic levels
- **Single trophic level:** Multiple species affected; entire trophic level changes
- **Multiple trophic levels:** Multiple species affected; multiple trophic levels change
- **Entire community:** Cascading effect that alters the entire ecosystem

	No impact	Species level	Single trophic level	Multiple trophic levels	Entire community
Dredging					
Port pile driving					
Increased boat traffic					
Infrastructure development					
Explosions					
Environmental accidents					

Resilience describes the average tendency of a species, trophic level, or community to resist changes in its natural state in response to a port activity. The ranking scheme refers to the resistance, reversibility and recovery of the ecosystem components that react to the hazard (ie. the functional level that was identified in the previous step)



- Resistance is the ability of the affected ecosystem components to remain unchanged.
- Reversibility is the ability of the affected ecosystem component to recover their ecological functions.
- Recovery time is the average time required for the affected ecosystem components to recover their ecological functions. For persistent hazards, we consider the recovery time following removal of the threat.

	Resistance	Reversibility of the consequences	Recovery time
Very high resilience	High	Reversible in less than a couple of weeks	Fast recovery in less than a couple of weeks
High resilience	High	Reversible in less than a couple of months	Recovery is less than a couple of months
Medium resilience	Medium	Reversible in less than one year	Recovery in less than one year
Low resilience	Low	Reversible in more than one year	Slow recovery in more than one year
Very low resilience	Low	Irreversible	No recovery possible

	Very low	Low	Medium	High	Very high
Dredging					
Port pile driving					
Increased boat traffic					
Infrastructure development					
Explosions					
Environmental accidents					

Certainty

Certainty is a qualitative measure of certainty that indicates the depth of knowledge used to determine vulnerability.

- **Not at all certain**
- **Low certainty:** Very little or no empirical work exists or the expert has limited personal experience
- **Moderate certainty:** Some empirical work exists or expert has some personal experience
- **High certainty:** Body of empirical work exists or the expert has direct personal experience
- **Very certain:** Extensive empirical work exists or the expert has extensive personal experience

	None	Low	Moderate	High	Very high
Dredging					
Port pile driving					
Increased boat traffic					
Explosions					
Environmenta					

I accidents					
Infrastructure development					

Consequence categories

Please assign a consequence category for each impact level.

- **Catastrophic:** Impact is clearly affecting the coastal dolphin population over a wide area, or affects more than one generation, or the impact is irreversible over a small area (nursing areas), or a sensitive part of the ecosystem is irretrievably compromised
- **Major:** Impact is significant at either a local or population level to the coastal dolphin populations, and might affect more than one generation.
- **Moderate:** Impact is present either at a local or population level. Recovery period within one generation is likely.
- **Minor:** Impact is present but not to the extent that it would impair the overall condition of the coastal dolphin population. Recovery period within one generation.
- **Insignificant:** No impact on the overall condition of the species or population

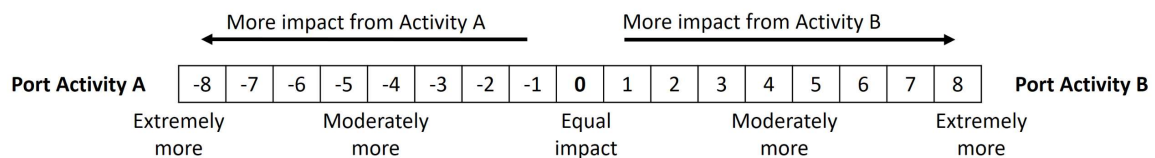
	Catastrophic	Major	Moderate	Minor	Insignificant
Increased turbidity due to <ul style="list-style-type: none"> - Dredging - Port pile driving - Increased boat traffic - Explosions - Environmental accidents - Infrastructure development 					
Noise pollution due to <ul style="list-style-type: none"> - Dredging - Port pile driving - Increased boat traffic - Explosions - Environmental accidents - Infrastructure development 					
Chemical pollution <ul style="list-style-type: none"> - Dredging - Port pile driving - Increased boat traffic - Explosions - Environmental accidents - Infrastructure development 					
Collisions due to <ul style="list-style-type: none"> - Dredging - Port pile driving - Increased boat traffic 					
Habitat destruction due to <ul style="list-style-type: none"> - Dredging - Port pile driving - Increased boat traffic - Explosions - Environmental accidents 					

- Infrastructure development					
Alternated bathymetry due to					
- Dredging					
- Port pile driving					
- Explosions					
- Environmental accidents					
- Infrastructure development					

Which other impacts due to port activities could affect coastal dolphin populations? Please identify activity and impact.

Pair wise comparisons of the port activities

To determine the relative impact of port activities, we ask you to indicate which of the activities bellow in your opinion has the highest impact on coastal dolphin populations. After each scoring you will also be asked how certain you are about this score.



If both activities equally affect coastal dolphin populations, give a score of 0.

If the activity at the LEFT side is more important, give a score between -1 and -8, with -1 to -3 being slightly more important, -4 to -5 being moderately more important and -7 to -8 being extremely more important.

If the activity at the RIGHT side is more important, you give a score between 1 and 8, with 1 to 3 being slightly more important, 4 to 5 being moderately more important and 6 to 8 being extremely more important.

Which activity has the highest impact on coastal dolphin populations?
How certain are you about the score you assigned?

Dredging

-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
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 Port pile driving

Certainty: None Low Moderate High Very high

Dredging

-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
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 Increased boat traffic

Certainty: None Low Moderate High Very high

Dredging

-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
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 Explosions

Certainty: None Low Moderate High Very high

Dredging	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Environmental accidents
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Dredging	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Infrastructure development
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Port pile driving	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Increased boat traffic
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Port pile driving	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Explosions
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Port pile driving	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Environmental accidents
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Port pile driving	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Infrastructure development
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Increased boat traffic	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Explosions
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Increased boat traffic	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Environmental accidents
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Increased boat traffic	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Infrastructure development
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Explosions	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Environmental accidents
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Explosions	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Infrastructure development
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	
Environmental accidents	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	Infrastructure development
	Certainty: <input type="radio"/> None <input type="radio"/> Low <input type="radio"/> Moderate <input type="radio"/> High <input type="radio"/> Very high																	

Provide your contact details here if you would like to receive the results of this survey:

To increase the effectiveness and scope of our study we are also interested in your recommendations of who of your peers and colleagues may have the expertise and knowledge to complete this survey. We ask that you nominate up to five additional experts so that the project team can contact them to invite them to participate in the study:

- 1.
- 2.
- 3.
- 4.
- 5.

Thank you for participating in this survey, your time and effort is highly appreciated.

Your responses and contact details will be strictly confidential, survey responses will not be identifiable to individuals in any way in any publication. Taking part in this study is completely voluntary and you have the right to withdraw. By submitting this form, you agree to participate as a respondent in this survey.

If you have any other remarks or questions related to this survey, you are invited to provide those here: