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Anthropogenic threat assessment of marine-associated fauna in Spencer Gulf, South Australia

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ABSTRACT

Assessing the vulnerability of species to anthropogenic threats is an essential step when developing management strategies for wild populations. With industrial development forecasted to increase in Spencer Gulf, South Australia, it is crucial to assess the ongoing effects of anthropogenic threats to resident and migratory species. Expert elicitation was used to assess 27 threats against 38 threatened, protected, and iconic marine-associated species. Species and threat interactions were assessed individually, and as taxonomic or functional groups. Climate change had the greatest overall exposure (c.f. risk) across species, followed by disturbance, pollution, disease/invasive species, and fishing/aquaculture threats. The largest overall sensitivities (c.f. consequences) were pollution and disease/invasive species, followed by climate change, disturbance and fishing/aquaculture threats. Vulnerability scores (exposure x sensitivity) showed the climate change group posing the greatest overall threat in Spencer Gulf, with individual climatic threats ranking as three of the top four biggest threats to most animal groups. Noise, shipping, and net fishing were considered the greatest region-specific individual threats to marine mammals; as were trawl fishing, line fishing, and coastal activities to fish/cuttlefish; trawl fishing, line fishing, and net fishing to elasmobranchs; and oil spill, disease, and coastal activities to sea/shorebirds. Eighteen of the 20 highest vulnerability scores involved the short-beaked common dolphin, Indo-Pacific bottlenose dolphin, and Australian sea lion, highlighting the particular susceptibility of these species to specific threats. These findings provide a synthesis of key threats and vulnerable species, and give management a basis to direct future monitoring and threat mitigation efforts in the region.

1. Introduction

Anthropogenic threat assessments are an essential consideration during the development of management strategies for marine and terrestrial populations. While direct assessments provide quantitative data on the impacts of specific threats to species (i.e. [1,2]), collection of such data on wide ranging and patchily-distributed species is time consuming, costly, and often impractical. In the absence of targeted quantitative data, expert elicitation can provide an alternative means to predict likely outcomes. Expert elicitation relies on informed experts providing their best estimates of the likely outcomes of scenarios, such as the effects of different threats on species. Opinions can be gathered independently from a panel of selected experts through structured questionnaires, known as the *Delphi* method, or obtained as the consensus of round-table discussions. Expert elicitation has been used to estimate the effects of threats on mammals and birds [3,4], seagrass [5], invertebrates and fishes [6], and to examine human threats to marine ecosystems on a global scale [7,8].

South Australia's Spencer Gulf (Fig. 1) is an ecologically significant region for many bird, mammal, fish, shark, and invertebrate species. It provides an important feeding area for migratory northern hemisphere shorebirds, whose numbers have declined in eastern Australia over recent decades [9], and encompasses significant portions of South Australia's breeding and foraging habitats for *endangered* raptor species [10]. Spencer Gulf similarly provides foraging and/or breeding grounds for resident dolphins such as bottlenose dolphins (*Tursiops* sp.), and

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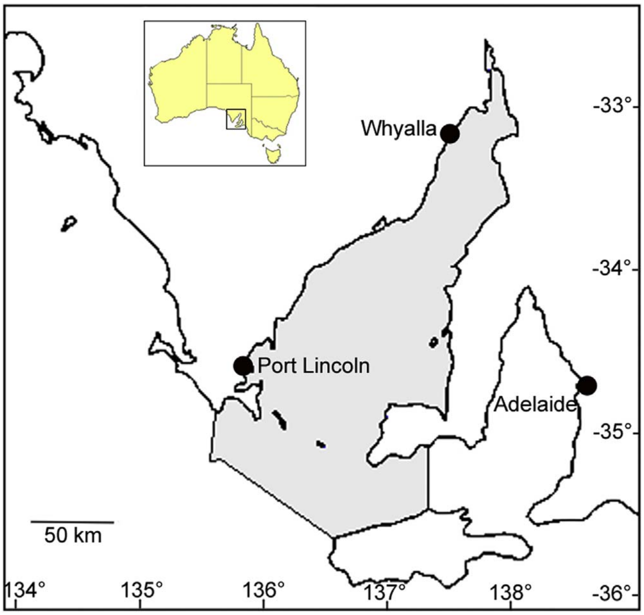

Fig. 1. Spencer Gulf and surrounding Investigator Strait in South Australia. Shading indicates the area considered in this study.

short-beaked common dolphins (*Delphinus delphis*); and migratory whales such as southern right whales (*Eubalaena australis*), and humpback whales (*Megaptera novaeangliae*) [11,12]. The region also contains important breeding and rookery areas for Australian sea lions (*Neophoca cinerea*) and long-nosed fur seals (*Arctocephalus forsteri*) [13,14]. Numerous shark and ray species inhabit Spencer Gulf [15], and important aggregation areas for white sharks (*Carcharodon carcharias*) and giant Australian cuttlefish (*Sepia apama*) are found in the region [16,17]. Spencer Gulf also contains a range of federally-protected syngnathid species [18].

Spencer Gulf also has a long history of human activities. Resident populations are found in towns along both sides of the Gulf, with many seasonal visitors each year. Multiple commercial fisheries operate in Spencer Gulf, with the largest fishery landing up to 32,000 tonne per annum in the region prior to the implementation of catch restrictions [19]. Spencer Gulf also encompasses 37% of the State's recreational fishing effort [20]. Long-term aquaculture for shellfish and pelagic finfish operate within Spencer Gulf alongside multiple vessel-based ecotourism businesses offering wildlife interactions with pinnipeds and white sharks [2]. The region is important for shipping, with hundreds of domestic and international cargo ships transporting mineral and agricultural products each year (see [22]).

As with any environment, the potential exists for human use to cause detrimental impacts to Spencer Gulf. Anthropogenic impacts to the marine environment span a wide range of stressors, including (but not limited to) over-exploitation, urban and industrial habitat degradation, pollution, debris, biosecurity, shipping effects, wildlife disturbances, and the ubiquitous impacts of climate change [8,21]. However, the extent and impacts of such threats to Spencer Gulf species are largely unknown, and significant interest exists to expand resource exploitation and subsequent infrastructure and shipping in the region [22]. Such developments will increase present-day anthropogenic pressures on local fauna, necessitating the need to assess current threats prior to developments commencing. Although data are available on the population dynamics, genetic structure, movements, and anthropogenic interactions of numerous marine species in Spencer Gulf (i.e. [2,14,23–25]), many threats and species are critically lacking assessments.

This study used the *Delphi* method to investigate the likely impacts of multiple anthropogenic threats on selected *Threatened, Endangered,* protected, and iconic species (TEPS) in Spencer Gulf. Species included cetaceans, pinnipeds, seabirds, shorebirds, sharks, rays, fish, and cuttlefish. To investigate the ongoing effects of threats, the study (1) quantified the likely exposures (c.f. risks) and sensitivities (c.f. consequences) of TEPS to threats within Spencer Gulf; (2) used this information to determine the vulnerabilities of TEPS to specific Spencer Gulf threats; (3) examined broad trends among threat types and species groups, (4) identified which individual threats posed the most hazard to different TEP groups; and (5) highlighted threat/species combinations with the highest vulnerability scores. This information will provide management with direction for future monitoring and threat mitigation efforts in the region.

2. Materials and methods

2.1. Variable selection

Using a combination of literature searches, meetings with stakeholders, and discussions with local scientists and managers, a list of 27 anthropogenic or anthropogenically-exacerbated threats deemed most likely to affect marine-associated species in Spencer Gulf was developed. Each threat consisted of multiple components (e.g. Wildlife Disturbance included boating activities, shark cage–diving operations, kayaking and dolphin watching) (Supplementary 1). A list of 38 marine-associated TEP species occurring in the region was also determined across the major animal groups (marine mammals, fish/cuttlefish (including seahorses), sea/shorebirds, and elasmobranchs) (Supplementary 2). Species were limited to those listed as *Threatened* or *Endangered* by the International Union for Conservation of Nature (IUCN), and protected or iconic species with known anthropogenic interactions within Spencer Gulf. Species with comparative demographics were grouped, resulting in 32 species/species groups (Supplementary 2). Appropriate Australian-based experts were identified from searches of published literature, Google Scholar™, Research Gate™, Government and University websites, and suggestions from other participants, with participants invited through email and professional association lists. The research was conducted under Human Ethics approval from the Social and Behavioural Research Ethics Committee, Flinders University (#70930).

2.2. Survey design and implementation

Surveys were conducted in two tiers. Participants familiar with the Spencer Gulf region estimated the frequency and likelihood of threat interactions with species (exposure surveys) (tier 1), while a wider range of experts independently assessed the likely outcomes of such interactions (sensitivity surveys; Supplementary 3) (tier 2). Knowledge of Spencer Gulf was considered essential to assess the likely exposures of species to threats; however, as there was no reason to suspect that the outcomes of such interactions in Spencer Gulf differ from similar interactions occurring elsewhere, local knowledge was not required for sensitivity assessments. Exposure and sensitivity surveys were undertaken electronically, either as an MS Excel file or a SurveyMonkey™ online questionnaire, with the order in which threats were presented randomised in online surveys.

Both exposure and sensitivity participants could assess multiple species, however each species had to be assessed individually. Each exposure and sensitivity survey consisted of multiple questions pertaining to the interactions between the species and the 27 Spencer Gulf threats under investigation. Threats were individually assessed in most survey questions, however some questions asked for a single answer which was applied across all threats (Supplementary 3). Participants were asked to answer all questions and assess all threats, but could omit answers when unsure. Descriptions of threats were provided in all cases, and experts were asked to consider the current status of threats, with the exception of climate change which used 2030 forecast values

Table 1
Mean exposure, sensitivity, and vulnerability scores per threat type and species group.

Threat type	Mean exposure score	Mean sensitivity score	Mean vulnerability score	Mean vulnerability score per species group			
				Marine mammals	Fish/ cuttlefish	Sea/ shorebirds	Elasmo-branchs
Climate change	27.0 (1.1)	5.6 (0.1)	40.9 (2.2)	67.3 (5.8)[a]	58.3 (6.2)	34.5 (1.9)	23.6 (2.9)
Disturbance	17.2 (0.8)	5.3 (0.1)	25.6 (1.6)	52.3 (4.3)[a]	33.6 (8.2)	20.6 (1.2)	9.6 (1.4)
Pollution	12.7 (0.8)	6.3 (0.1)	22.0 (1.7)	31.3 (4.9)[a]	26.6 (3.4)	25.3 (2.3)	8.4 (1.0)
Disease/ invasive species	10.5 (1.0)	6.4 (0.2)	18.1 (2.0)	17.6 (4.9)	17.2 (6.4)	28.8 (2.3)[a]	3.4 (1.0)
Fishing/ aquaculture	8.5 (0.6)	5.0 (0.1)	13.6 (1.3)	27.7 (4.0)[a]	25.7 (6.1)	5.3 (0.6)	10.6 (1.7)
All threats	15.0 (0.1)	5.5 (0.1)	23.3 (0.8)	41.2 (2.5)[a]	33.3 (4.6)	19.4 (0.9)	11.9 (0.9)

[a] indicates species group with the highest vulnerability score per threat type. Numbers in parentheses show standard errors of each mean estimate.

[26]. The lead authors were also available to answer any queries about the surveys.

Additional questions queried the participant's qualifications, experience in their field, experience with marine-associated fauna of the Spencer Gulf region, whether they wished to remain anonymous, and any comments regarding their threat assessments. At the end of the sensitivity surveys, participants were also asked to separately estimate their levels of confidence in assessing each threat and species in 25% increments (e.g. 0–25%, 25–50%, etc.). This question sought to ascertain the participant's level of familiarity with the threats and species, and was not asked on exposure questionnaires as almost all exposure participants also undertook sensitivity surveys (see results).

2.3. Analysis

Each survey question was ascribed a scale of 0–4 for analyses. As considerably more participants undertook sensitivity surveys, exposure and sensitivity surveys were analysed independently. Analyses began with the calculation of the total exposure or sensitivity score per threat in each survey. Each threat was considered separately, with the total exposure of each threat considered to be the cumulative chance of that threat overlapping and influencing the species. The answers to each exposure question were therefore multiplied for each threat to provide a total exposure score per threat for that survey (giving 27 total exposure scores per survey). Sensitivity scores were considered additive, where a lack of interaction with one component did not negate all consequences of that threat to the species. The answers to each sensitivity question were therefore summed for each threat to provide a total sensitivity score per threat for that survey (again giving 27 total scores per survey). With the exception of standard error calculations, any answers omitted in any surveys were ascribed the appropriate mean value for that threat/species/question combination from all other participants' scores. This allowed all experts' surveys to be included without affecting mean scores.

For each threat, the total exposure scores were then averaged across all surveys of the same species. This was repeated for the sensitivity surveys. This provided a single mean total exposure and sensitivity value for every threat/species combination (864 combinations for each, consisting of 27 threats by 32 species/species groups). Each mean total exposure score (range 0–64) was then multiplied by 0.25 to scale them equally with the sensitivity values (range 0–16), and mean total exposure and sensitivity scores multiplied together to produce a vulnerability score for each of the 864 threat/species combinations. The mean total exposure, sensitivity and vulnerability scores were then averaged across species groups and threat types to examine general trends. Participant confidence per species and threat were ascribed their range midpoints, and averaged across participants (e.g. each score of 0–25% was ascribed a value of 12.5). This gave a possible range of 12.5–87.5%, which was then rescaled to 0–100%. Mean standard errors for species and threats were calculated as the mean of the individual standard errors for each question.

3. Results

A total of 180 experts were invited to participate, with promotion on *BirdsSA*, *Oceania Chondrichthyan Society* and *Australian Marine Sciences Association* email lists yielding four additional participants. Three participants undertook exposure surveys only, 21 conducted both exposure and sensitivity surveys, and 78 participants conducted sensitivity surveys only. There were 3–7 exposure surveys conducted per species/species group (average = 3.9), and 8–21 sensitivity surveys conducted per species/species group (average = 12.8) (Supplementary 4). This provided a total of 125 exposure and 410 sensitivity surveys across the 32 species/species groups. Participants had an average of 17.9 years' experience in their field, and exposure survey participants had an average of 10.8 years' experience in the marine-associated fauna of the Spencer Gulf region. Over 84% of participants had, or were undertaking, a doctorate or higher degree, and consent to be identified with this study was given in 84% of cases (Supplementary 5).

3.1. General trends

To examine the general trends in the data, threats were grouped into five categories, species into four categories, and their mean total exposure, sensitivity, and vulnerability values examined. Climate change rated as the highest exposure threat (Table 1), due to its widespread overlap with the marine-associated species examined. The remaining threats were all considered to be region-specific (i.e. non-climatic threats which can be directly addressed through local actions in Spencer Gulf). Disturbance and pollution threats had the next highest exposures (Table 1), with both threats potentially occurring throughout Spencer Gulf, and thus increasing their likelihood of being encountered by multiple species. Disease/invasive species and fishing/aquaculture threats had the lowest exposure scores, suggesting they are encountered, and interact, less frequently. Average sensitivity values per threat group showed that disease/invasive species and pollution threats were thought to have the highest consequences when encountered (Table 1). Disturbance and fishing/aquaculture threats groups scored lowest, with a wide spread of individual values (Table 1; Supplementary 1). The pattern of group vulnerability scores followed a similar pattern to exposure group means, with climate change ranking highest, followed by disturbance, pollution, disease/invasive species and fishing/aquaculture threats. The marine mammal group had the highest average vulnerability score across all threats, and the highest vulnerability score per threat type for all but disease/invasive species, where the sea/shorebird group had the highest group vulnerability score (Table 1).

3.2. Individual threat effects

As management of Spencer Gulf will require more specific informa-

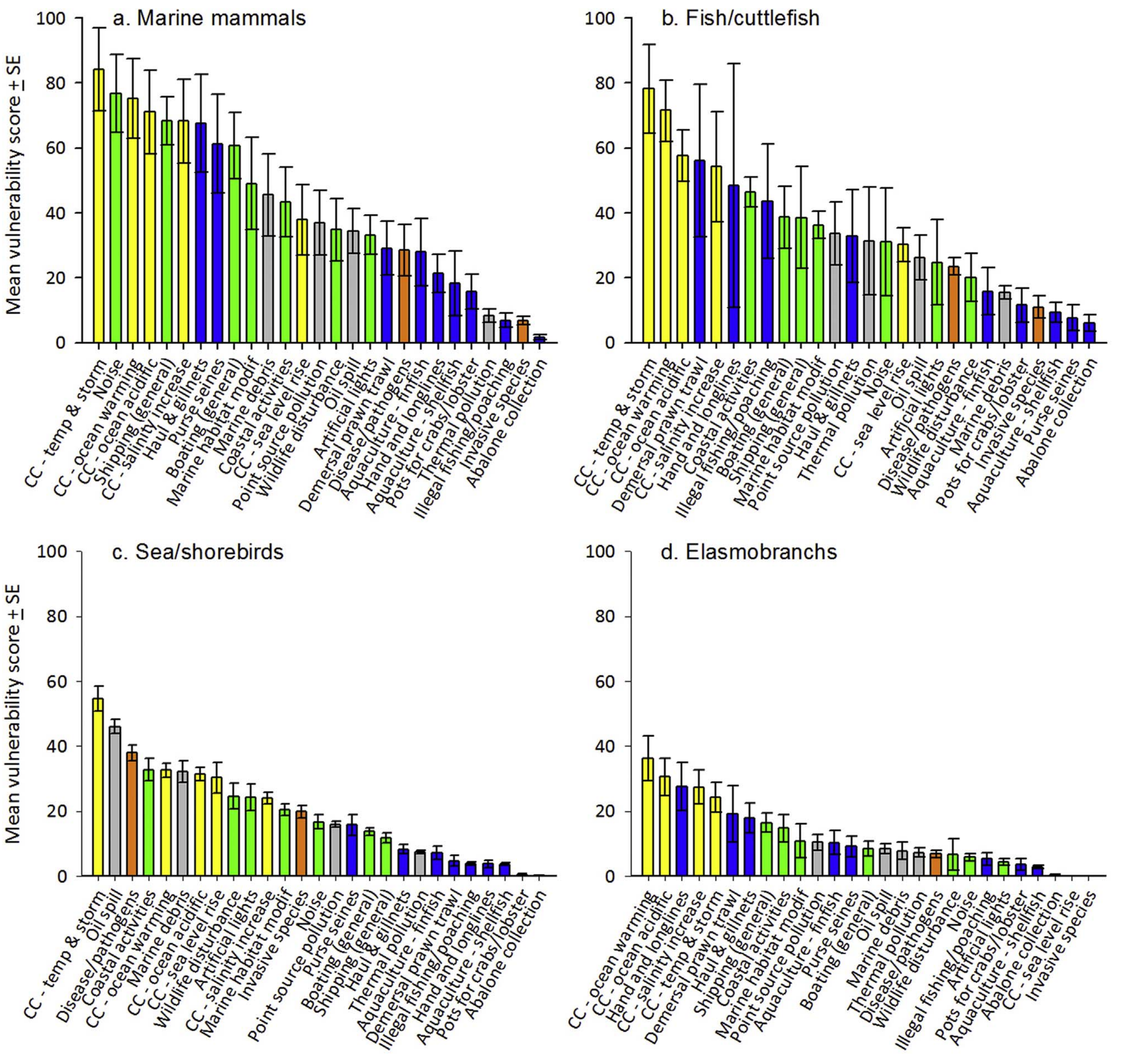

Fig. 2. Ranked mean vulnerability scores ± SE per species group. Colour bars indicate type of threat: yellow, climate change (CC); green, disturbance; grey, pollution; blue, fishing/aquaculture; orange, disease/invasive species. See Supplementary 1 for detailed threat information. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

tion than trends related to broad threat categories, the vulnerability scores of each of the 27 threats was individually examined for each species group. Almost all climatic threats assessed featured highly across all species groups, with extreme temperature and storm events ranking as the highest single threat for most species groups (Fig. 2a-d). Ocean warming, ocean acidification and salinity increase also ranked highly across the four species groups, while sea level rise was ranked as the lowest climate change threat for all but the sea/shorebird group (Fig. 2c). Although the fishing/aquaculture group of threats had the lowest mean vulnerability score overall (Table 1), some individual fishing threats featured highly in all but the sea/shorebird group (Fig. 2a-d).

A combination of climate change, disturbance and fishing threats dominated marine mammal vulnerability scores (Fig. 2a). These consisted of the regional threats of noise, shipping, haul and gillnets, and purse seine nets, in addition to multiple climate change threats. Both the fish/cuttlefish and elasmobranch groups had a pattern of climate change, fishing, then disturbance threats dominating their vulnerability scores (Fig. 2b, d), while the sea/shorebird group was subject to a different suite of threat rankings. Here, climate change and disturbance threats ranked lower than in the other groups, and fishing threats were thought to pose minimal hazard to this group (Fig. 2c). The regional threats of oil spill, disease and pathogens and coastal activities ranked highly for the sea/shorebird group, following extreme temperature and storm events. Although the likelihood of oil spill was deemed low in Spencer Gulf, its high ranking for sea/shorebirds was driven by the severe consequences to this group should it occur (Supplementary 1).

3.3. Individual threat/species interactions

To examine the likely impacts of individual threats to each Spencer Gulf species, the vulnerability scores of each of the 864 threat/species combinations were examined separately (Supplementary 6). Here, the likely impacts of 11 different threats on short-beaked common dolphins, Indo-Pacific bottlenose dolphins, and Australian sea lions produced 18 of the highest 20 individual vulnerability scores

Table 2
Highest 37 vulnerability interactions across all 864 threat/species combinations. Cells in bold indicate the highest 20 interactions. See supplementary 1 for threat abbreviations.

Threat category	Threat	Short-beaked common dolphin	Indo-Pacific bottlenose dolphin	Australian sea lion	Western blue groper	Giant Australian cuttlefish
Climate change	Temperature and storms	**112.6**	**130.9**	**110.5**	87.4	**95.9**
Climate change	Ocean acidification	**114.5**	**125.7**			
Climate change	Ocean warming	**110.2**	**126.5**	83.3	83.3	78.2
Climate change	Salinity increase	**106.5**	**126.5**			88.0
Climate change	Sea level rise			89.9		
Fishing/aquaculture	Hand and longlines				**122.3**	
Fishing/aquaculture	Haul & gillnets	**102.0**	**109.1**	**109.0**		
Fishing/aquaculture	Demersal prawn trawl					95.7
Fishing/aquaculture	Purse seines	**114.9**	92.2	87.4		
Disturbance	Boating	78.9	91.6	90.5		
Disturbance	Coastal activities		**98.2**			
Disturbance	Marine habitat modif	92.8	**109.1**			
Disturbance	Noise	**113.8**	**129.5**			
Disturbance	Shipping (general)	79.5	94.5	86.7		
Pollution	Marine debris			**99.4**		
Pollution	Point source pollution		79.4			

(Table 2). These species, along with the western blue groper and giant Australian cuttlefish also had the next highest 17 vulnerability scores (Table 2). Climate change threats were prominently represented across the marine mammal species, but had less impact on the western blue groper and giant Australian cuttlefish. *Purse seines* and *noise* threats were the highest regional threats for the short-beaked common dolphin, as was *noise* for the Indo-Pacific bottlenose dolphin. Australian sea lions were vulnerable to a range of regional threats, while the western blue groper and giant Australian cuttlefish each had high vulnerability to a specific fishing/aquaculture threat (Table 2). The subset of threats or species comprising the highest 37 vulnerability scores were also involved in the next highest 39 threat/species interactions (Supplementary 6), reinforcing the high vulnerabilities of these species, and the pervasive influence of these particular threats. These results also demonstrate that although examining group trends are useful, they can mask individual interactions of potential concern.

Participant confidence was highest for fishing/aquaculture threats, followed by disturbance, pollution, climate change, then disease/invasive species threats (Fig. 3a). Confidence was also generally high for the marine mammal species, followed by the sea/shorebirds, fish/cuttlefish, then elasmobranch species (Fig. 3b). The Melbourne skate and coastal stingaree had the lowest reviewer confidence of all species. These species also had the least information and published data available to participants. Fishing/aquaculture threats had the lowest variation across survey questions, followed by disturbance, climate change, pollution, then disease/invasive species threats (Fig. 3c). Mean standard errors varied more across species, and did not follow any apparent trend (Fig. 3d). Sea/shorebird species had the greatest range of mean standard errors, followed by elasmobranchs, fish/cuttlefish and marine mammals. Elasmobranch reviewers had the lowest overall variability per species, however this may be because reviewers were consistently conservative in their scoring due to their low confidence for many species.

4. Discussion

The use of expert elicitation allowed us to qualitatively assess the likely impacts of multiple regional and climatic threats on selected *Threatened, Endangered,* protected, and iconic cetacean, pinniped, seabird, shorebird, shark, ray, fish, and cuttlefish species in Spencer Gulf. Climate change is a potential threat to taxa around the globe [27], and was deemed the greatest threat group in the Spencer Gulf region. Extreme weather events can have catastrophic impacts on coastal seabird nesting and pinniped pupping [28–30], and recognition of this was reflected in extreme weather events ranking as the highest individual threat identified across most species groups. Climate change threats such as ocean warming and ocean acidification were also of high concern across all aquatic groups. These threats act in tandem [31], modifying fish and invertebrate development and growth [32,33], and disrupting prey detection in fish and sharks [34,35]. Sea level rise ranked lower across aquatic groups, however it ranked highly for the sea/shorebird group. The effects of sea level rise can negatively impact beach-nesting species such as the crested tern and Caspian tern, and impact essential intertidal foraging areas of migratory species such as red knots, curlew sandpipers, and other wader species [36].

Of the regional threats in Spencer Gulf (non-climatic threats which can be directly addressed through local actions), the greatest concerns for marine mammals centred predominantly around shipping and fishing activities. Shipping threats may impact marine animals through collision, anchoring, sediment disturbance, and waste discharge [37–39], and have the potential to affect both pelagic and benthic organisms in and around the path of the vessel. Similarly, noise from anthropogenic activities was assessed as being a potentially major threat to Spencer Gulf marine mammals. Cetaceans rely heavily on sound for foraging, communication and navigation [40,41], and anthropogenic noise can displace animals from an area, or in extreme cases inflict permanent damage to cetacean auditory tissues [42].

Marine mammals are also known to be impacted by fishing activities; demersal gillnet bycatch of Australian sea lions is considered the most critical threatening process for the species in the region [43,44], while short-beaked common dolphin interactions are known to occur with purse seine fisheries [45,46]. Ongoing strategies by the State Government have markedly reduced the reported mortality rate of short-beaked common dolphins in the sardine purse seine fishery operating in and around Spencer Gulf, although 126–303 animals were still reported as being encircled by fishing gears each year between 2010/11 and 2014/15 [46]. Continuing refinement of marine mammal management, including resources not available at the time of surveys [47,48], should aid in reducing future fisheries interactions, potentially reducing some of the interactions identified by participants in this study.

Although fishing/aquaculture was the lowest-ranking threat group overall, specific fishing threats dominated non-climatic fish/cuttlefish and elasmobranch vulnerability scores. The benthic-proclivity and habitat choices of giant Australian cuttlefish and syngnathids makes these species vulnerable to demersal prawn trawl capture [18,49], while blue groper species and giant Australian cuttlefish are known to be taken by line fishing [50,51]. These types of fishing gears have a similarly long history of interactions with various elasmobranch species [52,53], including captures in or near Spencer Gulf [54–56]. Although not a highly ranking threat, both white sharks and dusky sharks also had above-average interaction scores with finfish aquaculture in

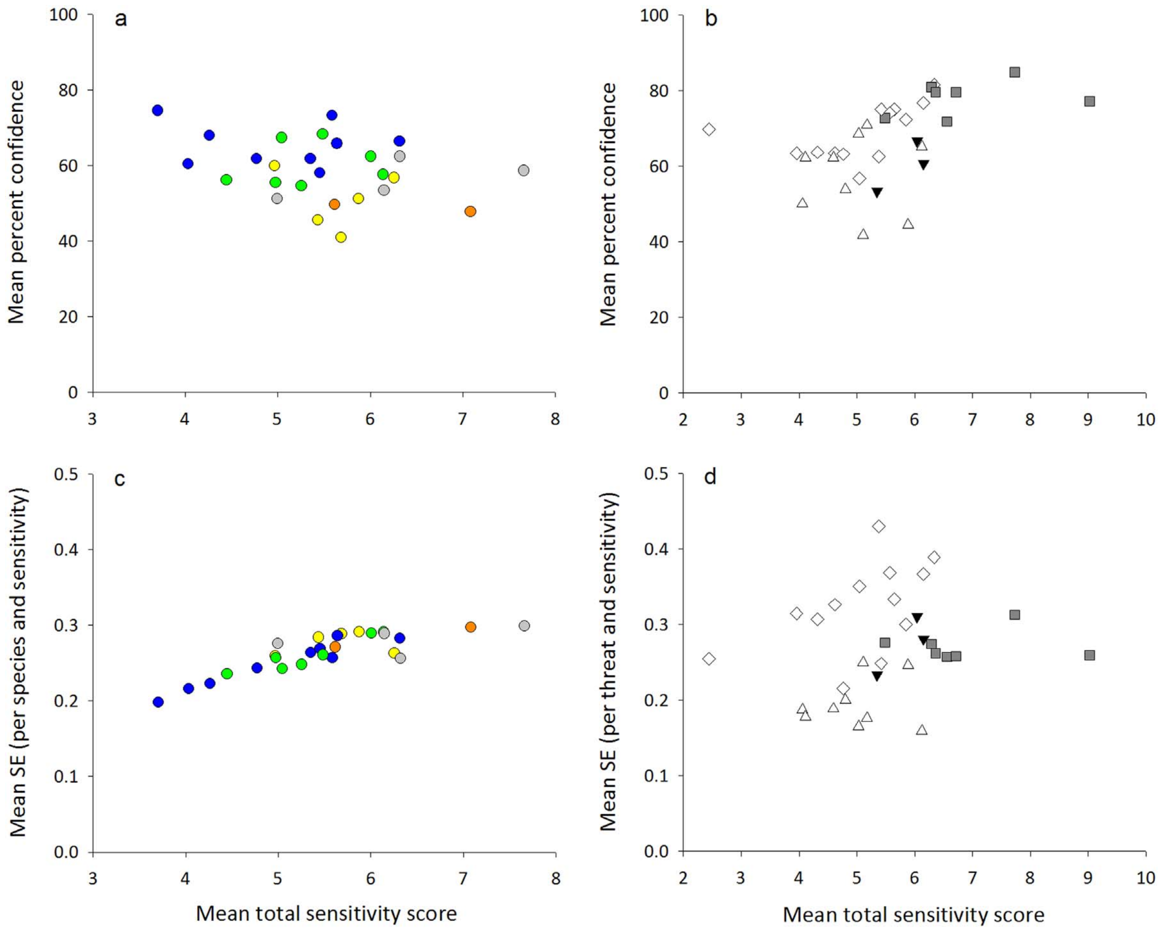

Fig. 3. (a, b) Mean participant confidence and (c, d) standard errors for each threat and species assessed. Circle colour indicates type of threat: yellow, climate change; green, disturbance; grey pollution; blue, fishing/aquaculture; orange disease/invasive species. Grey squares indicate marine mammals, white diamonds indicate sea/shorebirds, black inverted triangles indicate fish/cuttlefish and white upright triangles indicate elasmobranchs. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

Spencer Gulf. Instances of sharks entering finfish aquaculture pens have previously occurred in Spencer Gulf, prompting government workshops to investigate methods to reduce such interactions [55]. As with marine mammal fishery interactions, continued management refinements should help reduce future interactions within Spencer Gulf, and aid the future conservation status of these species in the region.

Seabirds and shorebirds are impacted by a different suite of threats to the other species groups, with infrequent regional events such as oil spill and disease thought to be more hazardous than most climatic threats. Oil spills can have catastrophic effects on birds, including severe reductions in thermal insulation and flight performance, embryonic mortality, and poisoning [57–59]. Meanwhile, diseases and pathogens can spread rapidly among birds, as many species carry bacteria and ectoplasmic ticks which can be transferred by individual contact [60,61]. Other prominent threats identified in surveys, such as human disturbance and coastal developments, can impact multiple activities of birds, such as nesting and foraging [62–64]. Surveys also identified marine debris as ranking highly for sea/shorebirds, moderately for marine mammals, and of low concern for fish/cuttlefish and elasmobranchs. Marine debris is an increasing global issue for many species, including seabirds [65], with effects including reduced body condition, fatal entanglements, and plastic-derived chemical poisoning [66].

Marine mammals were deemed the most vulnerable species group in Spencer Gulf, with elasmobranchs deemed the least. Both groups have demographies constrained by internal fertilization and prolonged lifespans [67,68]. However, marine mammals' requirement to breathe air increases their exposure to surface threats, which elasmobranchs may avoid. Moreover, the behaviour of pinnipeds to haul themselves out of the water also exposes these species to land-based threats. The lack of published data for some elasmobranch species was a concern to some participants (*pers obs*), and while a lack of empirical data is the reason for expert elicitations, it is intuitive that knowledge of species' demography or biology will provide more meaningful assessments. Unfortunately, such basic information was not available for the Melbourne skate or coastal stingaree, requiring assessments to be based on knowledge of similar species. This may explain why assessments of these two species had the lowest confidence. Although life-history data are available for many of the Spencer Gulf elasmobranch species [15], most of it comes from outside the region. Increasing local biological knowledge of these species is therefore important to improve the accuracy of their assessments within Spencer Gulf.

The life history traits of marine mammals may also explain their particularly high vulnerability to certain climate change threats. Climatic changes may significantly impact the spatial range and seasonal abundance of Australian marine mammals, with short-beaked common dolphins, Indo-Pacific bottlenose dolphins, and Australian sea lions all potentially exhibiting distributional shifts and declines of local populations if key cold-water habitats are reduced [69]. Such shifts can affect species interactions, changing the composition and structure of local marine mammal communities and ecosystem function (e.g. [70]). The giant Australian cuttlefish also appears to be vulnerable to multiple climate change impacts, particularly those affecting shallow water. Their benthic eggs are attached to rocks in relatively shallow water, and adults aggregate in shallow waters to breed, which offers little protection from climatic effects, or from targeted fishing activities such as prawn trawling in these areas [16]. However, the key breeding area for giant Australian cuttlefish in Spencer Gulf is closed to the taking of all cephalopods, limiting fishing impacts in the area.

As 95% of participants surveyed species within a single taxonomic group (marine mammals, fish/cuttlefish, sea/shorebirds or elasmobranchs), it is possible that preconceived biases, or particular personal experiences may have inflated or deflated species scores. Participant biases are a limitation of this type of assessment [71,72], and the design of this study attempted to reduce such effects by ensuring high survey numbers while limiting responses to suitably qualified experts. Participants invariably assessed the response of their species to all 27 threats, resulting in any participation biases applying across all threats (i.e. participants giving consistently higher or lower threat scores). Thus, even if the absolute threat scores have some bias, the relative ranking of threats in each survey should be retained. By assessing threat risks to each species group separately, the effects of this type of potential bias was further minimized.

Expert elicitation can provide valuable information to help direct future management and research strategies in the absence of empirical data (i.e. [3,4,6]). Translation of this study's findings into management plans could potentially take many different forms for Spencer Gulf. Focusing future efforts on the most vulnerable species, or the regional threats with the largest overall impacts would provide broad-scale benefits. Reducing multiple threats simultaneously is more efficient than focusing on single threats [7], however, addressing such threats would be logistically and financially challenging across a large geographic scale such as Spencer Gulf. Alternatively, efforts to reduce threat impacts could focus on regional threat/species combinations with the highest vulnerability scores. Such a highly-targeted approach would be more feasible to implement, and would reduce the interactions of greater concern. In addition, targeting future research efforts towards addressing data deficiencies may be another useful application of these findings: empirically determining the outcomes of threat/species interactions, where possible, could quantify the impacts of threats on species; or simply obtaining regional biological data would improve our understanding of local ecology and the likely impacts of Spencer Gulf threats, especially for lesser-studied species. The choice of approach is up to management; however, no matter the approach, the data derived here is an important first step towards local threat mitigation efforts in the future.

5. Conclusion

This study provides a comprehensive assessment of the potential impacts of multiple anthropogenic threats on marine-associated *Threatened*, *Endangered*, protected, and iconic species in Spencer Gulf. In addition to identifying the general trends of threats to Spencer Gulf marine-associated fauna, this study ranks and identifies differences in the impacts of individual threats to different species groups, identifies marine mammals as being the most vulnerable species group, highlights a subset of marine mammals, western blue groper and the giant Australian cuttlefish as being particularly vulnerable to specific threats, and draws attention to data deficiencies in the elasmobranch group. The findings here can direct management strategies in the region, and provide a guide to focus future research efforts. Both are critically important for minimizing the potential impacts of future developments on marine-associated species in the Spencer Gulf region.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2017.03.036.

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