Spencer Gulf Ecosystem & Development Initiative

Interactions between whales and vessels: causes and mitigation options – with reference to southern Australia

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Disclaimer

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Report to be cited as

C Izzo and BM Gillanders. 2015. Spencer Gulf Ecosystem and Development Initiative. Interactions between whales and vessels: causes and mitigation options – with reference to southern Australia. Report to the Board of the Spencer Gulf Ecosystem and Development Initiative. February 2015. 39 pages.

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Executive summary

The purpose of this report is to develop a collective understanding of the potential impacts of shipping on whales with particular reference to Spencer Gulf.

Whales in Australian waters are protected under the *Commonwealth Environment Protection and Biodiversity Conservation (EPBC) Act 1999*, with five species listed as nationally threatened. Recovery plans are in place for these five species and have identified vessel disturbance through collision or disruption of whale behaviour as a factor that may limit recovery of whale populations. Developments are therefore required to submit proposals for assessment under the EPBC Act.

To consider shipping and whales in the Gulf, we reviewed (1) industry assessment reports and government notifications that had been referred under the EPBC Act, (2) data for whale population numbers, sightings and movements in Spencer Gulf, (3) published literature on whales and vessel strikes from throughout the world, and compared (4) shipping traffic and reported whale strikes in Australia.

Six development proposals in Spencer Gulf have been referred for assessment with several proposals not considered controlled actions. Of those considered a controlled action, two have been approved subject to conditions including the need to consider whales further. Two others have not yet been approved.

Eighteen species of whales/dolphins have been recorded in Spencer Gulf, although no species permanently reside in the Gulf and many species are seen infrequently. Southern right whales and humpback whales are the key whale species found in the Gulf, with indications that they are becoming more common.

Interactions between whales and vessels are well documented in the Northern Hemisphere, but less well known in Australian waters. Significant uncertainties exist as to the impact of ship strikes on Australian whale populations as ship strike databases are relatively recent. Rates of whale-vessel interactions for right whales are, however, a fraction of those found in South African waters or the North Atlantic and represent a small component of the total mortality rates.

The likelihood and severity of a whale-ship strike interaction is influenced by factors that can be broadly categorised as vessel-specific, whale-specific and geographic. Although all vessel sizes (recreational and commercial) have been involved in collisions, the majority involve large vessels (>50 m length). Increased ship speed also increases the likelihood of interaction. Whales that swim near the surface and calves in particular are most vulnerable. Several global hotspots have been identified where ship strikes are more frequent, but these do not include Australia.

Mitigation measures have been used to reduce the frequency of collisions between vessels and whales. Four common strategies are (1) increasing awareness and detection of whales, (2) alert signals, (3) reducing the co-occurrence of vessels and whales, and (4) reducing vessel speeds. Studies assessing the effectiveness of mitigation strategies are limited, with long-term monitoring required.

In Australian waters whale populations are not as at risk to ship strikes as their Northern Hemisphere counterparts. However, with continued development of maritime infrastructure and increases in shipping capabilities there is a need for pro-active management of vessel traffic around critical whale habitat. Ideally such management would involve minimal operational and economic impact to vessel

operators. For management of whale-vessel interactions to be effective a better understanding of spatial and temporal distribution and movement patterns is required such that critical habitat and/or seasonal migratory pathways can be determined. Lower speeds of vessels (in the Gulf) are also likely to decrease the risk of whale and ship interactions.

Background

Australian waters are home to around 45 species of cetacean species (whales, dolphins and a porpoise), all of which are protected under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (the EPBC Act) in Commonwealth waters (*i.e.* from the 3 nm State limit to the boundary of the exclusive economic zone). Whales and dolphins are also protected within State and Territory waters. Five species of whales are listed under the EPBC Act as nationally threatened, because commercial whaling has resulted in a reduction in their numbers. These include three species, sei, fin and humpback whales, listed as vulnerable and two species, blue and southern right whale, listed as endangered. Recovery plans are in place for these five species.

Whale recovery plans generally identify a series of threats including entanglement, vessel disturbance, whaling, climate variability and change, noise interference, habitat modification and overharvesting of prey (Bannister *et al.*, 1996). A risk matrix is then used to determine the impact on specific whale populations taking into consideration the likelihood of occurrence and the consequences of the threat. Vessel disturbance through collision or disruption of whale behaviour ranges from recreational vessels through to large commercial vessels and are considered anthropogenic factors which may limit the recovery of some whale populations. Southern right whales are the key species involved in vessel collisions in the southern hemisphere, although recorded numbers are low (Kemper *et al.*, 2008b; DSEWPC, 2013).

Besides protection through the Australian Whale Sanctuary and State government threatened species legislation, other protection measures include marine bioregional plans and a series of guidelines for various industries, for example seismic guidelines for the petroleum industry, national guidelines for whale (and dolphin) watching and methods to minimise the impact of fishing. A ship strike mitigation strategy to reduce the likelihood of interactions between whales and vessels in Australian waters is currently being developed. In addition, environmental impact assessment processes under the EPBC Act and state legislation are required to consider whales (DSEWPC, 2013).

The purpose of this report is to develop a collective understanding of the potential impacts of shipping on whales[1] with particular reference to Spencer Gulf. Our aims were to:

(1) Review industry assessment reports and government notifications by reviewing referrals within the public sections part of the EPBC Act;
(2) Review relevant data for whale population numbers, sightings and movements in South Australia including Spencer Gulf;

[1] Dolphins and porpoises are not considered in this review.

(3) Review peer-reviewed published literature on whales and vessel strikes from throughout the world;
(4) Compare shipping traffic and reported whale strikes in Australia.

Industry assessment reports and government notifications

The following site was searched for referrals relevant to Spencer Gulf in South Australia: http://www.environment.gov.au/cgi-bin/epbc/epbc_ap.pl?name=invitation_to_comment&limit=999&text_search

A brief summary of the notifications and assessments can be found in Appendix A. Several proposals were not considered controlled actions therefore no further report was required. Expansion of the Olympic Dam mine was approved subject to a series of conditions, as was the Port Spencer export facility. The Port Bonython iron ore bulk commodities export facility and the Central Eyre iron projects have not yet been approved. Both approved proposals were required to consider whales, notably southern right whales, in further detail.

Whale population numbers, sightings and movements in South Australia

In South Australia, 33 species of whales, dolphins and a porpoise, and nine species of pinnipeds (true seals, fur seals and sea lions) have been recorded since the late 1800s (Kemper *et al.*, 2008a; Gibbs and Kemper, 2014). Cetaceans in South Australia are important to the local Aboriginal culture as well as historically to colonial whaling enterprises. Currently, in South Australia all cetacean species are protected under the State *National Parks and Wildlife Act 1972*, the *Fisheries Management Act 2007*, as well as the EPBC Act (Gibbs and Kemper, 2014).

A number of whale species occur in such low numbers in Australia and are sighted infrequently such that their extent of occurrence and area of occupancy can not be determined, for example fin and sei whales. Other species such as blue whales and humpback whales have extensive distributions and behaviours in Australian waters (Figs. 1 to 4). The distribution of blue whale, for example, is determined by productive feeding grounds such as areas of upwelling (e.g. Bonney upwelling in South Australia: Gill *et al.*, 2011).

In Spencer Gulf, a total of 18 species have been recorded, however, no whale species permanently reside in the Gulf, with southern right whales and humpback whales seasonally inhabiting the southern region of the Gulf in winter (Figs. 1 & 2) (Gibbs and Kemper, 2014). Incursions into Spencer Gulf are generally attributed to breeding-related migrations, *e.g.* in the case of the southern right whale, moving from feeding grounds in the Southern Ocean to the head of the Great Australian Bight and to Fowlers Bay near the southern tip of the Eyre Peninsula (Carroll *et al.*, 2011). As

Spencer Gulf is relatively shallow (< 60 m depth), deep-water species, such as the sperm whale and blue whale, are rarely recorded in the Gulf (Figs. 3 & 4)(Bannister *et al.*, 1996; Gibbs and Kemper, 2014).

There is little known about the abundances or population structuring of whales specific to South Australia. In general, Australian whales appear to be recovering post industrial whaling, with many populations attaining rates of recovery often at their theoretical maximum, e.g. southern right whale and humpback whale (Carroll *et al.*, 2014a; Harcourt *et al.*, 2014). However, recovery appears to vary among species and populations. For example, there are marked differences in recovery and abundances between southern right whales in south-western and south-eastern Australia, with the populations numbering approximately 3,000 and 500 individuals, respectively (Carroll *et al.*, 2014a).

In relation to Spencer Gulf, sightings of southern right whales and humpback whales are becoming increasingly more common in the Gulf, providing indirect evidence that South Australian abundances of these species are increasing (Gibbs and Kemper, 2014). In tandem with population recoveries, whale populations are likely to expand their distributions and may recolonise former calving and foraging grounds (Rayment *et al.*, 2012; Torres *et al.*, 2013; Carroll *et al.*, 2014b); this may in part explain increased sightings of southern right whales and humpback whales in the northern reaches of Spencer Gulf, e.g. off Port Augusta and Whyalla (www.sawhalecentre.com/sightings) (Figs 1 & 2). Increases in the numbers and spatial ranges of whales in Spencer Gulf may increase the likelihood of further overlap with shipping traffic.

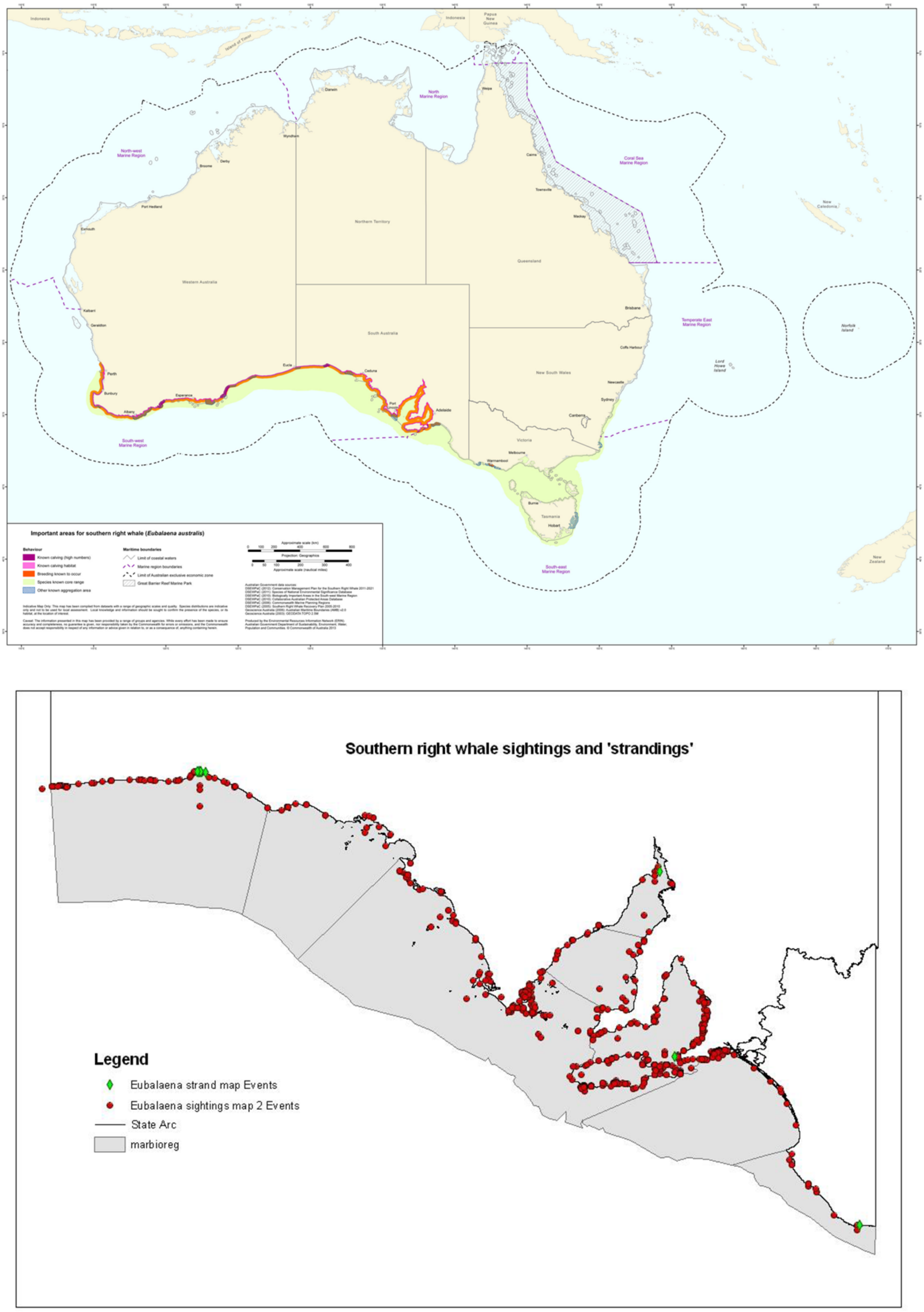


Figure 1. Australian distribution of the southern right whale (top). Map downloaded from Department of Environment website http://secure.environment.gov.au/coasts/species/cetaceans/australia/index.html. Recorded sightings and strandings of southern right whales in South Australia included in the databases of the South Australian Museum (as of 2007) (bottom). Figure from Kemper (2008).

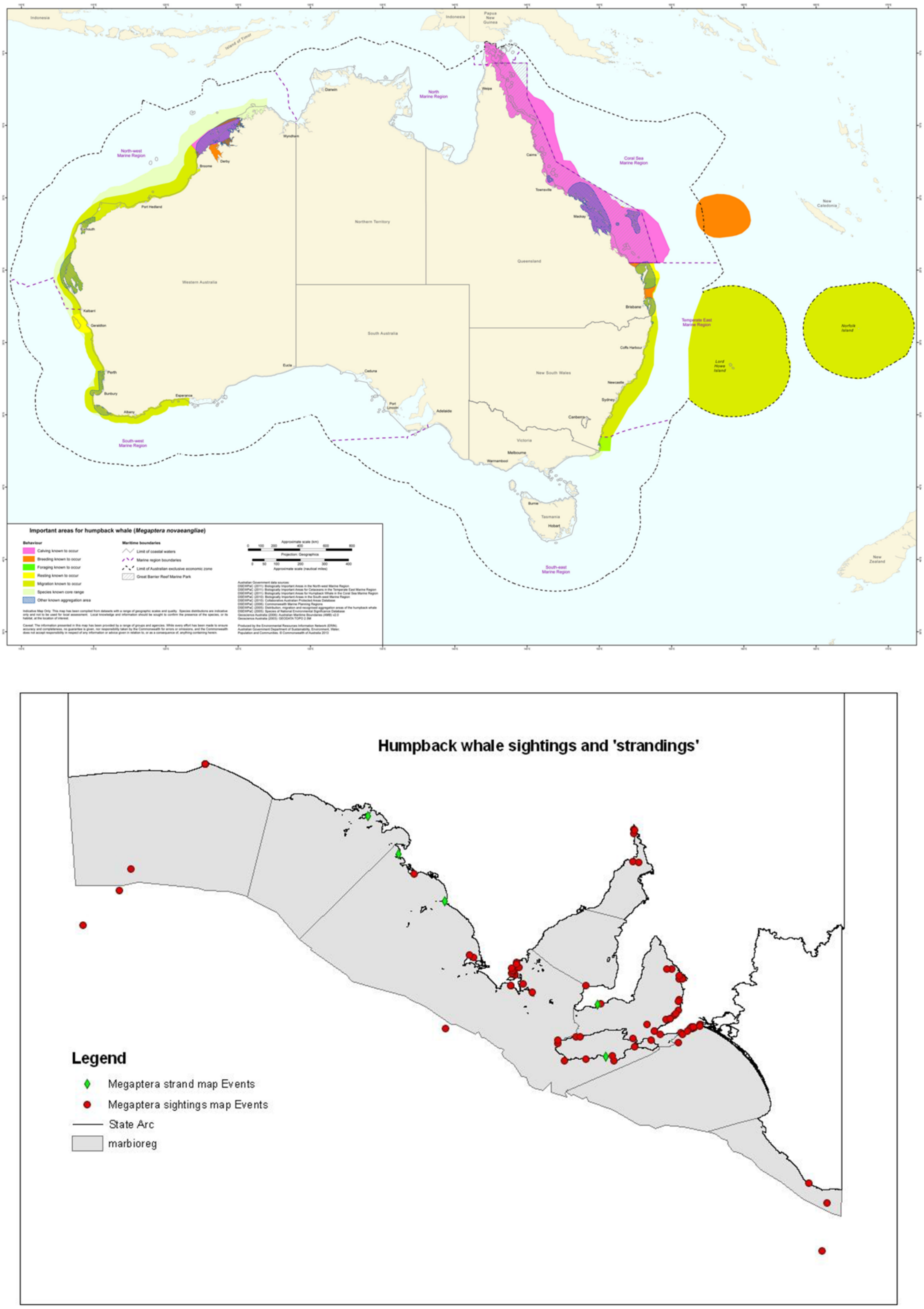
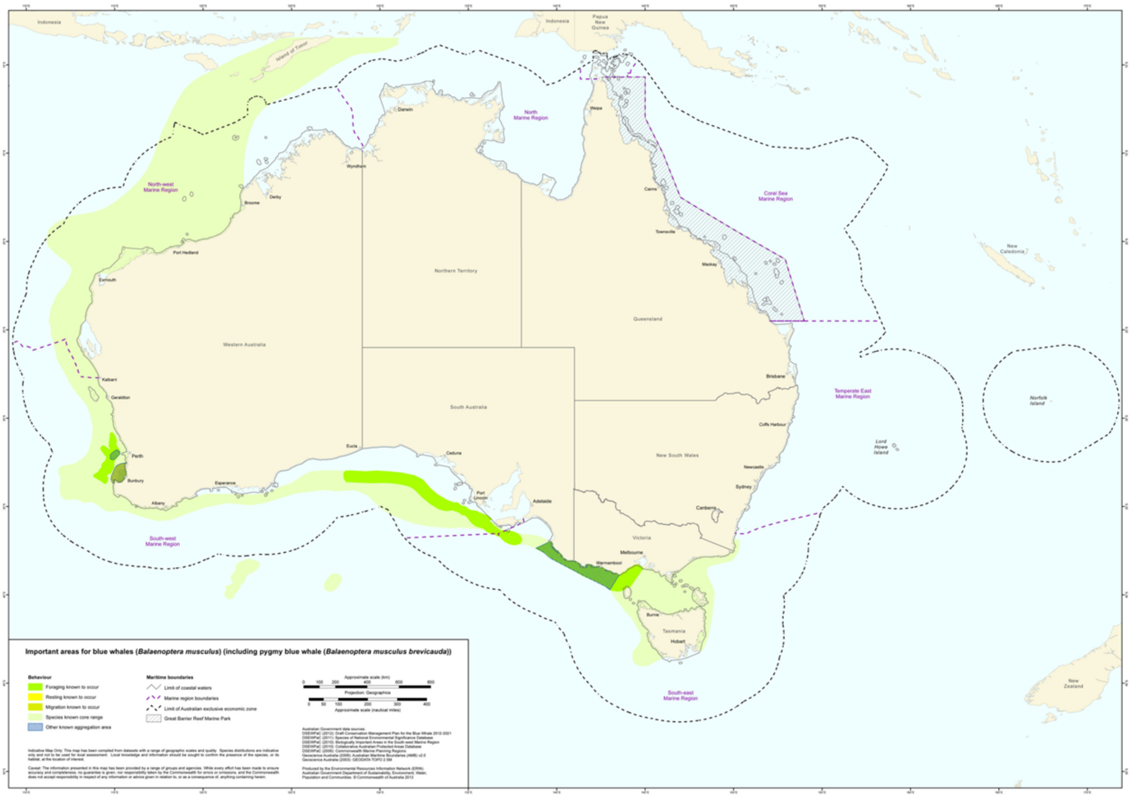


Figure 2. Australian distribution of the humpback whale (top). Map downloaded from Department of Environment website http://secure.environment.gov.au/coasts/species/cetaceans/australia/index.html. Recorded sightings and strandings of humpback whales in South Australia included in the databases of the South Australian Museum (as of 2007) (bottom). Figure from Kemper (2008).



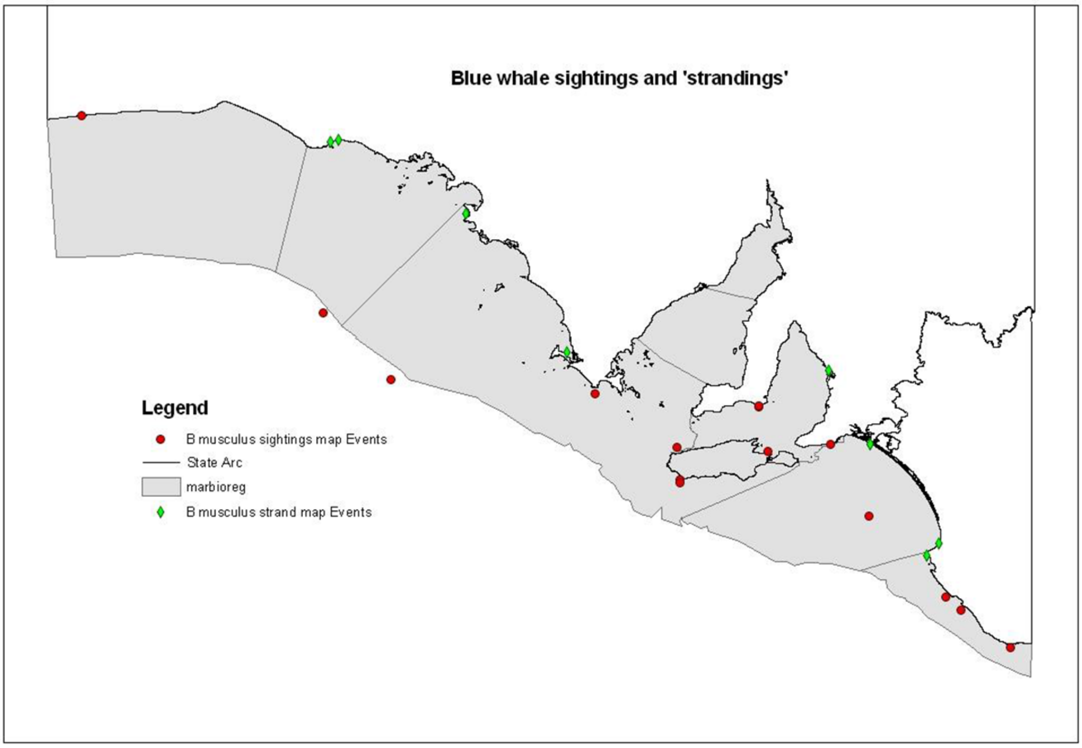
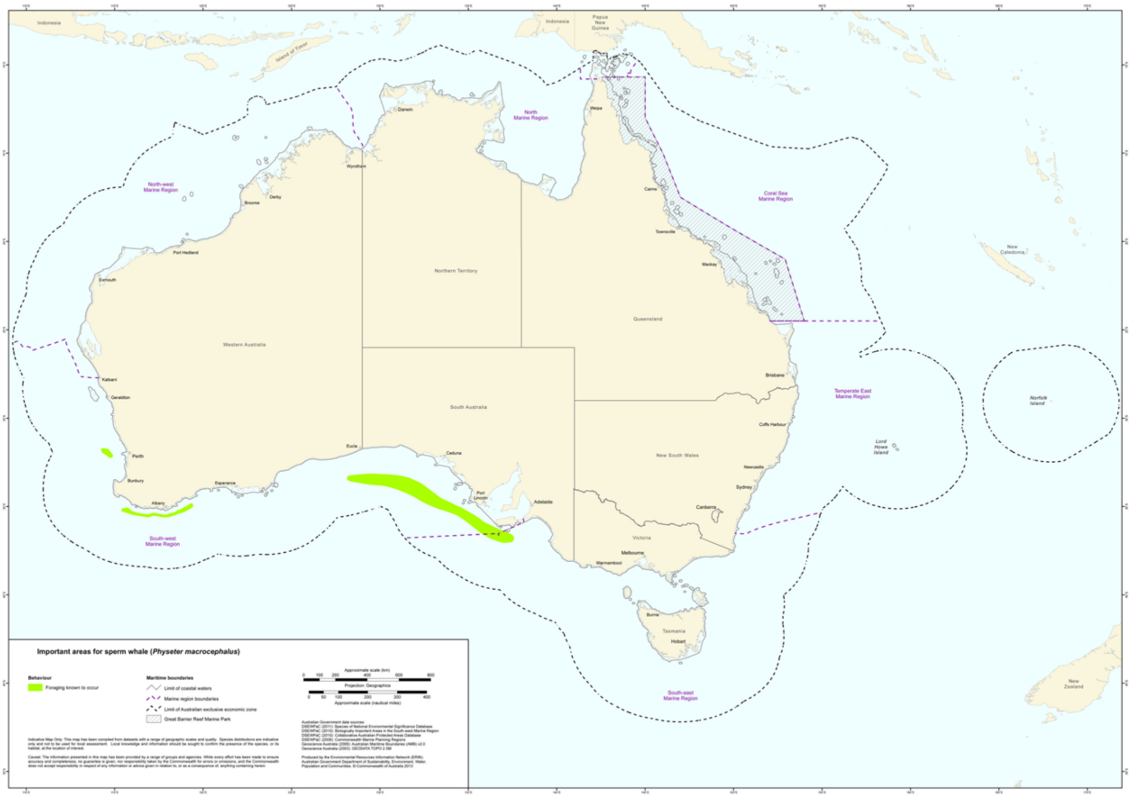


Figure 3. Australian distribution of the blue whale (top). Map downloaded from Department of Environment website http://secure.environment.gov.au/coasts/species/cetaceans/australia/index.html. Recorded sightings and strandings of blue whales in South Australia included in the databases of the South Australian Museum (as of 2007) (bottom). Figure from Kemper (2008).



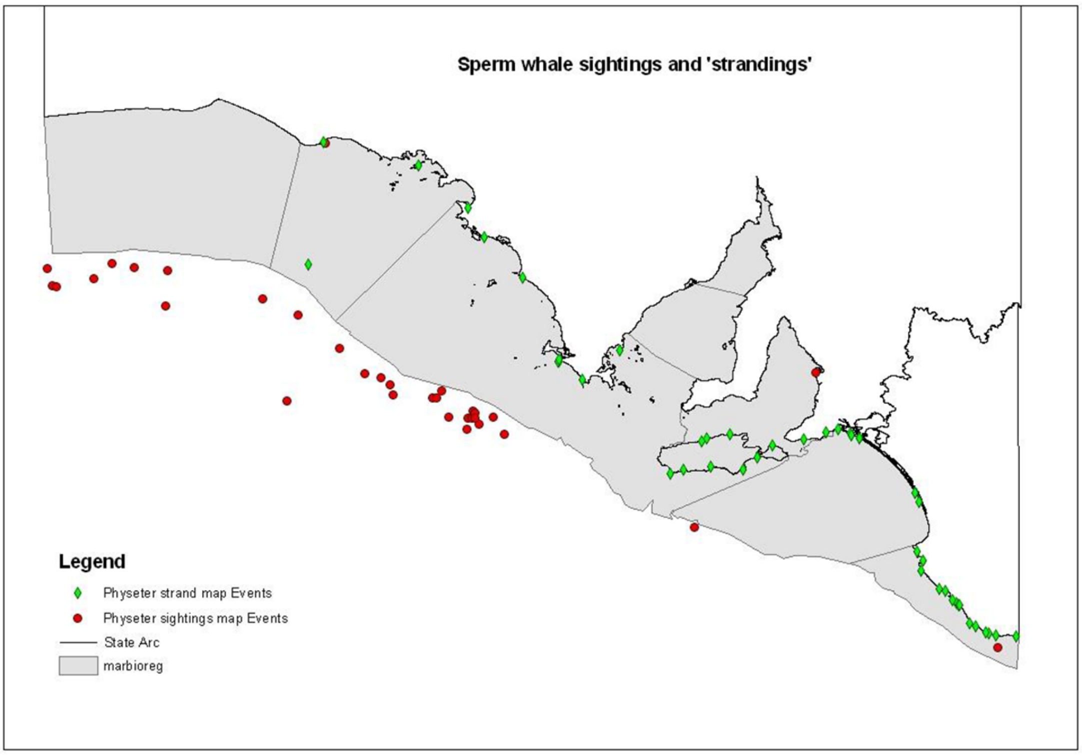


Figure 4. Australian distribution of the sperm whale (top). Map downloaded from Department of Environment website http://secure.environment.gov.au/coasts/species/cetaceans/australia/index.html. Recorded sightings and strandings of sperm whales in South Australia included in the databases of the South Australian Museum (as of 2007) (bottom). Figure from Kemper (2008).

Whales and shipping: What is known for Australian waters?

Ship strikes are well-documented in the Northern Hemisphere (*i.e.* the United States, Canada and the Mediterranean Sea); however, in Australian waters interactions between whales and vessels are not well documented (Bannister *et al.*, 1996; Kemper *et al.*, 2005; Van Waerebeek *et al.*, 2007; Kemper *et al.*, 2008b).

The direct outcome of a ship strike for the whale is generally death or serious injury, including fractured bones, haemorrhaging, or propeller lacerations (Knowlton and Kraus, 2001; Campbell-Malone *et al.*, 2008; Conn and Silber, 2013). Non-fatal collisions likely have long-term negative effects on the survival of individuals (Silber *et al.*, 2009) and the injuries sustained may ultimately result in the death of the cetacean, even several years after the collision (Campbell-Malone *et al.*, 2008). Even passive interactions between whales and vessels (*i.e.* whale watching) elicit short-term changes in whale behaviour, including changes to pod composition (Ribeiro *et al.*, 2005), surfacing and diving patterns (Blane and Jaakson, 1994; Gulesserian *et al.*, 2011), as well as movement patterns and habitat use (Williams *et al.*, 2002; Bejder *et al.*, 2006).

Collisions with whales can also pose a threat to human safety, with reports of ship strikes resulting in serious injury (including two fatalities) of passengers and crew members (Laist *et al.*, 2001; de Stephanis and Urquiola, 2006; Carrillo and Ritter, 2010). In addition, the vessel itself may sustain considerable damage, potentially leading to economic losses for shipping companies as well as damage to the public image of the company in terms of environmental impacts (Laist *et al.*, 2001; Couvat and Gambaiani, 2013).

In Australia three species of large whales, the southern right, humpback and Bryde's whales' appear to be most vulnerable to ship strikes (Van Waerebeek *et al.*, 2007; Kemper *et al.*, 2008b), with mortalities related to regional differences in whale abundances. For example, the majority of ship strikes on Australian southern right whales have been reported at the central and western bounds of the species' Australian distributions, where the densest aggregations form (Burnell and Bryden, 1997; Kemper *et al.*, 2008b). These regions are also associated with higher shipping densities (Fig. 5) (Ducruet and Notteboom, 2012; Goldsworthy and Goldsworthy, 2015), suggesting that hotspots of whale and vessel co-occurrence are evident in Australia, though at lower rates relative to the Northern Hemisphere.

With increasing numbers of humpback and southern right whales wintering in Australian coastal waters, interactions with vessels involving these two species are likely to become more frequent. The effects of ship strikes on cetacean populations will be exacerbated where shipping and recreational boating overlap with critical habitats, such as calving and nursing sites, and along migration routes.

Australia, being geographically remote from major world suppliers and markets, relies heavily on maritime trade, with shipping being the main mode of transport for Australia's exports and imports. In 2012-13 the total weight of freight through Australian ports was 1.1 billion tonnes (BITRE, 2014) (AMSA, 2010). Over the last decade freight volumes passing through Australian ports have grown by 83.8% (6.3% annually), and are expected to increase annually by 5.1% over the next 20 years (BITRE, 2014).

Relative to global shipping densities (Fig. 5), Australia constitutes approximately 1.5% of international imported cargo (shipping statistics reported at www.worldshipping.org/about-the-industry/global-trade/trade-statistics: note Australia was not ranked within the top 20 exporting countries in 2009-10). Nevertheless, shipping traffic in Australian waters has increased by 130% over the ten years to 2008-09, and is expected to continue to grow into the foreseeable future (AMSA, 2010).

In South Australia, Port Adelaide is the major hub for exports and imports of containerised (*e.g.* cars and general cargo) and non-containerised (*e.g.* gas and minerals) cargoes to and from South Australia to domestic and international trading regions. In 2013-13, the total volume of freight through Port Adelaide was 23.2 million tonnes (approximately 2% of the Australian total), representing a 6.6% per annum increase over the last 14 years (BITRE, 2014). Forecasted Port Adelaide freight is expected to increase by 4.6% annually over the next 20 years to 27.3 million tonnes in 2032-33 (BITRE, 2014). In terms of Australian shipping traffic, South Australia and Spencer Gulf experience moderate levels of maritime traffic (Figs. 5 & 6). Nevertheless, within Spencer Gulf hot spots of shipping traffic can be observed in the northern (near Whyalla) and southern zones (near Port Lincoln) of the Gulf (Fig. 6).

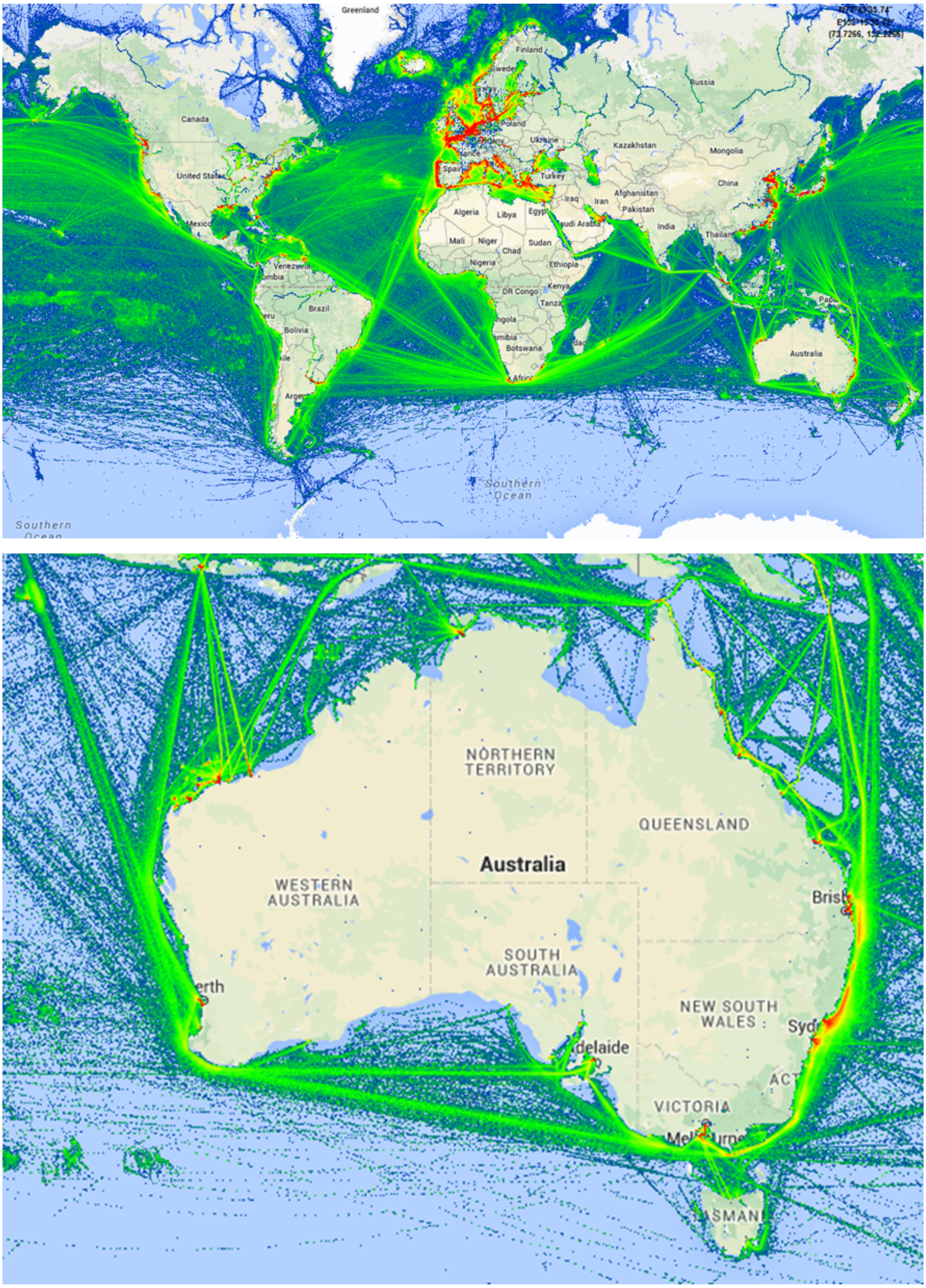


Figure 5. Map of global (top) and Australian (bottom) shipping routes based on received Automatic Identification System data. Areas of high shipping traffic are shown in red. Map generated from http://www.marinetraffic.com/en/

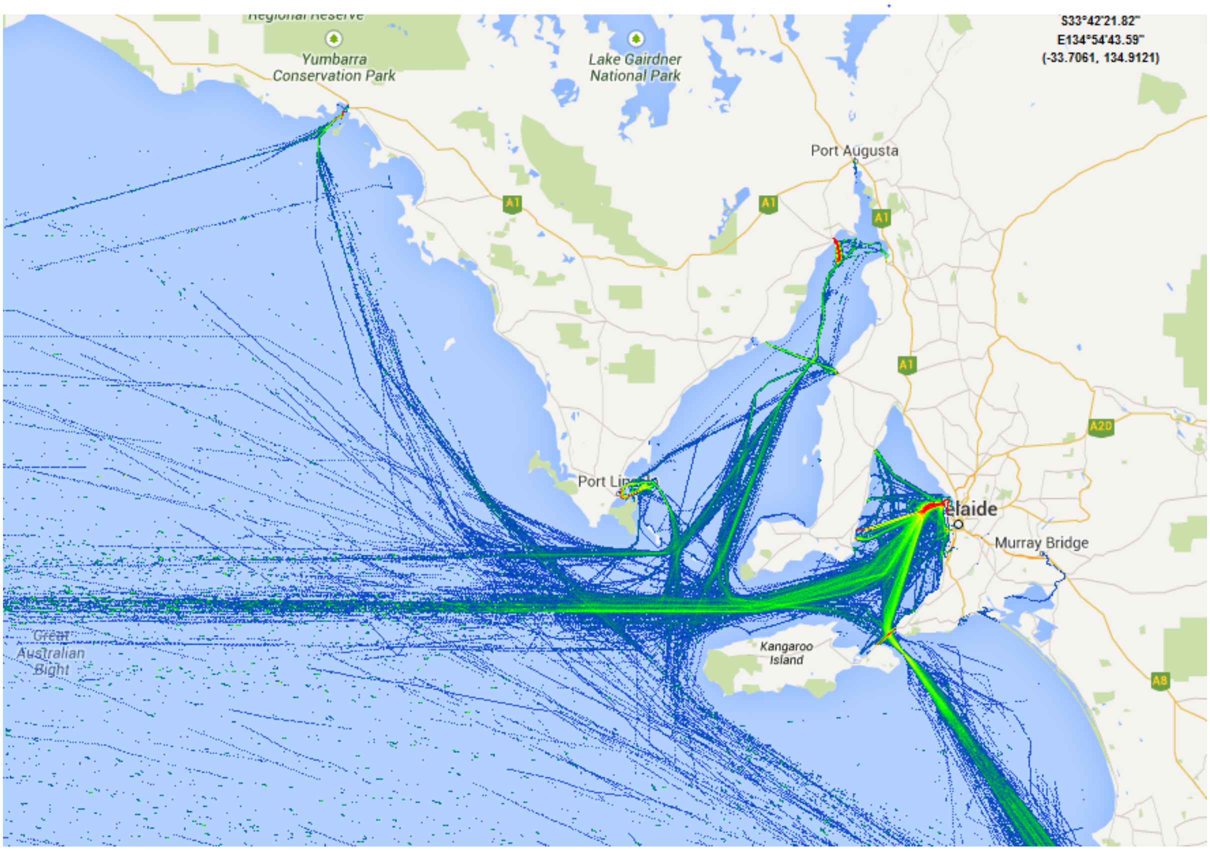


Figure 6. Map of shipping routes in and adjacent to Spencer Gulf, South Australia, based on received Automatic Identification System data. Areas of high shipping traffic are shown in red. Map generated from http://www.marinetraffic.com/en/

Currently, impacts of ship strikes on Australian whale populations cannot be assessed with any precision due to reporting uncertainties (Bannister *et al.*, 1996; Kemper *et al.*, 2005; Van Waerebeek *et al.*, 2007; Kemper *et al.*, 2008b). The development of an easily accessible online database system (see the International Whaling Commission's efforts: https://iwc.int/ship-strikes) will provide an invaluable tool to estimate the risk of collisions between vessels and whales and develop appropriate protection measures. Several such databases exist internationally (e.g. Laist *et al.*, 2001; Jensen and Silber, 2004; Van Waerebeek *et al.*, 2007). A ship strike database was established for Australian waters by the Australian Marine Mammal Centre (https://data.marinemammals.gov.au/), which should assist future studies in assessing risks of interactions between whales and vessels in Australian waters.

When data are available, it may be possible to estimate annual ship strike rates. Using mortality data reported in Kemper *et al.* (2008b) for southern right whales in Australia and South Africa as well as for North Atlantic right whales, annual rates of whale-vessel interactions were calculated at 0.09 $year^{-1}$, 0.34 $year^{-1}$ and 0.76 $year^{-1}$, respectively. These differences are likely due to there being lower densities of both whales and shipping traffic in Australia relative to the other regions (Fig. 5) and/or due to lower reporting rates of ship strikes (Van Waerebeek *et al.*, 2007; Kemper *et al.*, 2008b; Moore, 2009). Using the same data presented in Kemper *et al.* (2008b), it is also possible to approximate total mortality rates of the Australian southern right whale (*i.e.* by combining natural and anthropogenic attributed mortalities) allowing for comparisons between ship strike mortality rates (0.09 $year^{-1}$) with total mortality rates (0.79 $year^{-1}$). Thus, ship strike mortality rates are a fraction of total mortality rates.

Few direct ship strike risk assessments have been undertaken for Australian whale populations. For humpback whales a modelling exercise for Australian waters estimated that as a worse case scenario 7 whales per annum could be affected by vessel interactions (Collie, 2011). This estimate was based on recent whale abundance and distribution data, and shipping traffic densities. It compares to annual collision estimates of 25 humpback whales in the Abrolhos Bank, Brazil (Bezamat *et al.*, 2014), and 20 humpback whales in British Columbia, Canada (Williams and O'Hara, 2010). Similarly, the predicted risk of collision for southern right whales in southern Australia indicates relatively low risks of collision (Fig. 7). The threat of ship strikes to southern right whales is considerably less than that for North Atlantic right whales (Ward-Geiger *et al.*, 2005; Knowlton and Brown, 2007; Torres *et al.*, 2013). In combination with the low numbers of reported ship strikes, these studies suggest that the risk of collisions between whales and vessels in Australia is low and as such vessel induced mortality is unlikely to pose an immediate threat to Australian whale populations (Kemper *et al.*, 2008b).

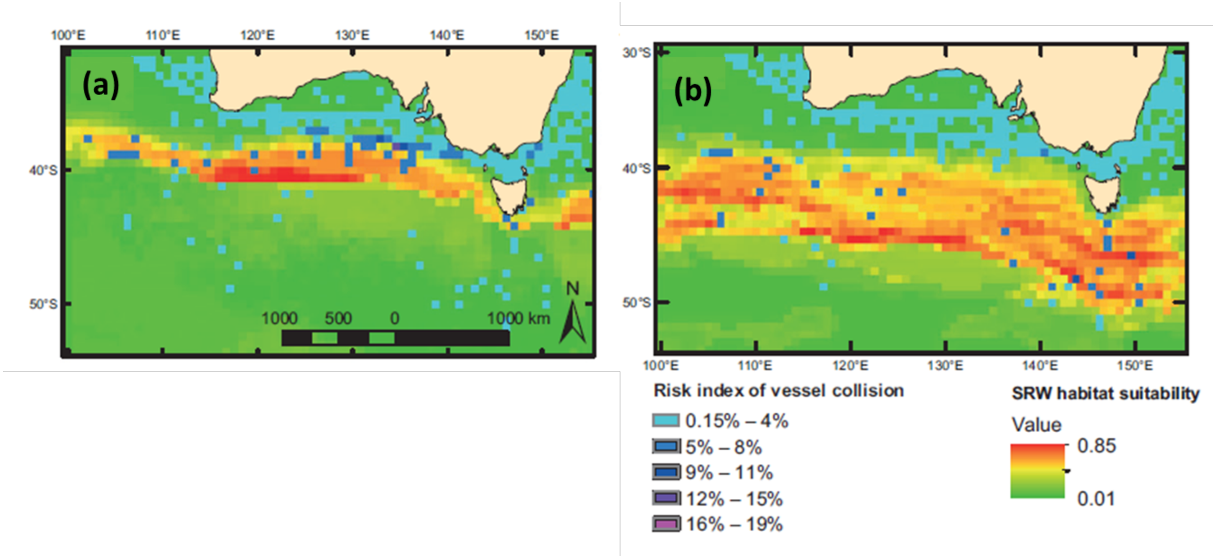


Figure 7. Predicted risk of collision between ships and southern right whales in southern Australia in the austral spring (a) and austral winter (b). Colour scales indicate habitat suitability and collision risk. Figure from Torres *et al.* (2013).

In Australia, where there is potential for the expansion of shipping traffic and maritime construction (*e.g.* around the critical humpback whale breeding grounds on the Great Barrier Reef Marine Park: Smith *et al.*, 2012), it is important that management measures are considered in advance in order to minimise the increased risks of collisions between whales and vessels (Reeves *et al.*, 2012). In this instance, managers in Australia can learn from the mitigation measures adopted in the Northern Hemisphere.

Review of published literature on whales and vessel strikes

A literature search was undertaken using the online Web of Science search tool (search conducted on 27th May 2014). Web of Science is an online academic database from ISI Web of Knowledge® that provides access to information from over 8,700 research journals. The defined search terms were: (*whale* OR *cetacea**) AND (*strike**), where the asterisks acts as a wildcard allowing all derivatives of the terms "*cetacea*" and "*strike*" to be identified. A total of 207 references published between 1984 and 2014 were identified. Of these, 18 references were excluded as they were either irrelevant and/or duplicates, resulting in 189 papers that were reviewed in greater detail.

Of the 189 papers, 92 (48.6%) were directly related to ship strikes, with a clear increase in the numbers of papers published through time (Fig. 8). The majority of these references related to the Northern Hemisphere, with only 4 (4.3%) of the references specific to the Southern Hemisphere. This Northern Hemisphere bias was further highlighted at the species levels, whereby 18 (19.5%) of the references specifically referred to northern right whales (including the North Atlantic population).

This publication bias presumably reflects the greater potential for interactions between shipping and whales in the Northern Hemisphere where shipping traffic is greater.

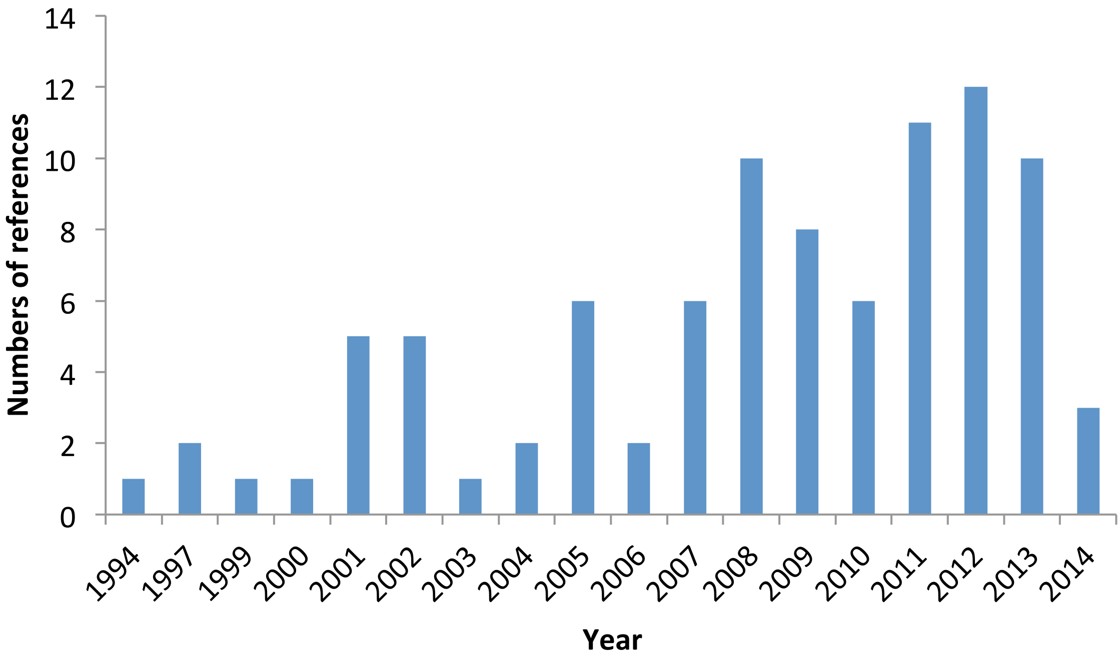


Figure 8. Number of whale ship strike publications between 1994 and 2014. The decrease in 2014 reflects the date range of the search which was up to 27th May 2014.

The numbers of papers identified by the Web of Science search tool reflects a portion of the available literature related to collisions between whales and vessels, as there is a large volume of material published (and available online) as grey literature (*i.e.* technical and internally published government or other reports). As required, additional publications including grey literature were incorporated into the subsequent document, but many of these have not been peer-reviewed. Where peer-review has occurred it is often done within an organisation.

Factors influencing interactions between whales and ships

While ship strikes on whales have been documented since the 1800s (Reeves *et al.*, 2002), there has been a marked increase in the frequency of collisions from the 1950s onwards, corresponding to a period when vessels rapidly increased in size and speed (attaining speeds > 14 knots: Laist *et al.*, 2001). In parallel, the numbers of vessels have also increased steadily, with global shipping activity increasing by 5% per year between 1950 and 2010 (a 17-fold increase in that time period: Stopford, 2009), with further increases in global shipping traffic forecast over the next few decades (Southall, 2005; Ducruet and Notteboom, 2012).

Generally, ship strikes occur when either whales or vessel operators fail to detect one another in time to avoid collision, with a number of factors influencing the likelihood and severity of a collision event (Dolman *et al.*, 2006). These factors, which may act independently or in combination can be broadly categorised as being: (*i*) vessel-specific, (*ii*) whale-specific, and (*iii*) geographical (Dolman *et al.*, 2006).

Vessel-specific

Almost all vessel sizes and classes have been involved in collisions with cetaceans, including small vessels (jet skis) and non-motorised sailing vessels (Laist *et al.*, 2001; Jensen and Silber, 2004; Ritter, 2012). However, the majority of reported fatal or serious whale injuries involved large vessels (> 50 m length: Laist *et al.*, 2001); which is likely due to sheer size and bulk of these vessels, whereby visibility close to the bow of the vessel is more likely to be limited and when a whale is spotted, there is not sufficient time to alter the vessels course (Dolman *et al.*, 2006; Silber *et al.*, 2009). In the same manner, increased ship speed has also been shown to increase the risk of collisions (Conn and Silber, 2013), as both the vessel and whale are provided less opportunity to identify and avoid one another (Vanderlaan and Taggart, 2007; Carrillo and Ritter, 2010). Vessel speed has been implicated as a key factor in determining the severity of vessel strikes to whales (Laist *et al.*, 2001; Tsukrov *et al.*, 2009; Conn and Silber, 2013), with collisions occurring at 15 knots having an 80% likelihood of resulting in whale death (Vanderlaan and Taggart, 2007) (Fig. 9). In addition, increased vessel speeds increase the hydrodynamic draw of vessels, which may result in whales being drawn towards vessels making them more vulnerable to collisions (Silber *et al.*, 2010).

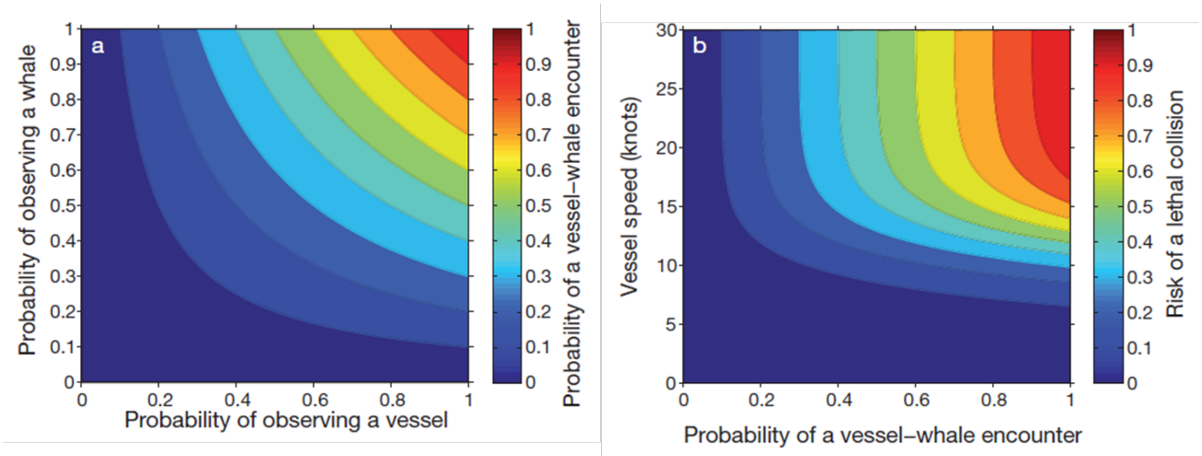


Figure 9. Nomographs illustrating (a) the generalised 0.1 probability of observing a vessel and a whale at the same time and location, and (b) the risk of a lethal collision as a function of the vessel speed. Figure from Vanderlaan *et al.* (2008).

Whale-specific

In general, all species of whales are vulnerable to ship strikes largely due to their characteristic surface or near-surface behaviour for feeding and breeding as well as sleeping (e.g. Mayo and Marx, 1990; Miller *et al.*, 2008; Parks *et al.*, 2012). Calves may be particularly vulnerable as they spend most of their time at the surface (Ward-Geiger *et al.*, 2005; Dolman *et al.*, 2006; Van Waerebeek *et al.*, 2007; McGillivary *et al.*, 2009). In addition, some individuals/populations also potentially exhibit a habituation and attraction to vessels (e.g. Corkeron, 1995; Stone and Yoshinaga, 2000), or decreased response to vessel interactions, particularly when engaging in biologically-important activities (*e.g.* feeding, breeding, sleeping) (Carrillo and Ritter, 2010; Williams *et al.*, 2011). These behaviours all act to increase the likelihood of increasing the concurrence of whales and vessels, increasing the potential for ship strikes.

Geographical factors

Several global hot spots have been identified where ship strikes may affect the status of cetacean populations (Silber *et al.*, 2012). These include the east coast of the United States of America (Knowlton and Kraus, 2001; Douglas *et al.*, 2008), the Mediterranean Sea (Panigada *et al.*, 2006), the Strait of Gibraltar (de Stephanis and Urquiola, 2006), and the Canary Islands (de Stephanis and Urquiola, 2006; Ritter, 2010). These areas are characterised by a substantial overlap between high levels of shipping traffic (Fig. 5) and a known high density of cetaceans (Carrillo and Ritter, 2010).

Most collisions appear to occur on the continental shelf (Laist *et al.*, 2001), reflecting the overlap between high densities of whales and vessels. As such, resident coastal populations appear to be especially vulnerable to ship strikes as there appears to be little immigration even among adjacent populations (Clapham *et al.*, 2008). To a lesser extent whales inhabiting offshore water may also be affected, as would seasonally abundant whale populations and the migration corridors if there are sufficient densities of vessels (Panigada *et al.*, 2006; Ritter, 2010).

Mitigation measures used throughout the world

The frequency of collisions between vessels and whales and the potential threat to whale populations (especially in the face of increased vessel traffic: Southall, 2005), have made ship strikes a principal conservation issue (Silber *et al.*, 2012). Hence, various collision mitigation strategies have been initiated in an attempt to reduce the incidence of ship strikes.

Evaluating the effectiveness of initiatives to prevent the incidence of ship strikes is of considerable importance, particularly, as it has been suggested that some strategies have marginal or no efficacy (*e.g.* Wiley *et al.*, 2008; van der Hoop *et al.*, 2013). However, studies assessing the effectiveness of established ship strike mitigation strategies are largely limited by the logistical constraints of working with data poor systems (*i.e.* irregular ship strike incidences both pre-and post-management: Gende *et al.*, 2011; Pace, 2011) and due to the short time frame that some of these measures have been put into place (generally < 5 years: Conn and Silber, 2013; Mullen *et al.*, 2013; van der Hoop *et al.*, 2014). Moreover, mitigation strategies are largely established on a case-by-case basis, which may require detailed assessment (refer to Silber *et al.*, 2012; Couvat and Gambaiani, 2013) and may not be directly applicable to other regions. Continued long-term monitoring is required to aid in assessing the effectiveness of measures to reduce the incidence of ship strikes. Nevertheless, here we provide a brief overview and assessment of the efficacy of four commonly identified ship strike mitigation strategies: (*i*) increasing awareness and detection of whales; (*ii*) sound stimuli; (*iii*) reducing the co-occurrence of vessels and whales; and (*iv*) reducing vessel speeds.

Increasing awareness and detection of whales

In order to reduce the risk of a collision between whales and vessels, it is important to ensure that vessels are made aware of the presence of whales that are in close proximity (Reeves *et al.*, 2007). The detection range of a large cetacean should be long enough (several thousands of metres) so that the vessel operators can take the appropriate avoidance actions (Silber *et al.*, 2009). For example, detecting a whale 600 m away at a speed of 40 knots affords a reaction time of 30 seconds before collision, whereas, if detected 2500 m away at a speed of 40 knots, a vessel has two minutes to react to the presence of a whale (Carrillo and Ritter, 2010).

Trained observers, both on-board vessels and in aircraft, can aid in reducing ship strikes by detecting animals early enough so collisions between whales and ships are avoided (Hain *et al.*, 1999; Panigada *et al.*, 2010). Trained observers detect whales more easily and efficiently than the untrained (David *et al.*, 2011) and are capable of detecting an animal at distances > 400 m in optimal weather conditions (Weinrich *et al.*, 2010). In addition, observers can also provide data on whale distributions and associated environmental conditions (Panigada *et al.*, 2010). However, visual surveys may only effectively detect a small percentage of the whales present.

Alternatively, a range of technologies focused on enhancing whale detection and reducing collisions are available (*e.g.* sonar, radar, enhanced remote visual detection). The effectiveness and feasibility of various technical approaches have been reviewed in detail elsewhere (see Silber *et al.*, 2009; Couvat and Gambaiani, 2013). In general, these technologies are capable of reducing the risks of ship strikes; however, due to the costs associated with maintaining these systems, as well as some inherent technical limitations (*e.g.* restricted detection ranges, false detections), environmental constraints, as well as significant ecological concerns (*e.g.* increased environmental acoustic loading), none of these technologies are regarded as an optimal means of reducing ship strikes (Silber *et al.*, 2009; Carrillo and Ritter, 2010; Couvat and Gambaiani, 2013). Passive acoustic technologies (*i.e.* those that capture sound from the environment) are considered one of the most promising for addressing ship strikes (Silber *et al.*, 2009); however, these devices are only capable of detecting vocalising whales, and if not in a multi-array configuration cannot provide location details for the whale. Future endeavours to apply several technologies in combination would likely increase field of detection, providing sufficient early warnings to mariners to improve the likelihood or avoid collisions between whales and vessels.

Alert signals

In some documented collisions between whales and vessels, individual whales swimming parallel to a vessel have turned directly into the path of the ship (Allen *et al.*, 2012). Similarly, some whale species display no or delayed avoidance reactions to oncoming vessels, including diving shortly before the vessel reached them or remaining at the surface in close proximity to the vessel (Watkins, 1986; Nowacek *et al.*, 2004; Bezamat *et al.*, 2014). These behaviours suggest that some species of whales may be unable to correctly detect and/or locate ships (Tehhune and Verboom, 1999; Gerstein *et al.*, 2005; Allen *et al.*, 2012), or they have become habituated to the sounds of approaching vessels (Laist *et al.*, 2001; Nowacek *et al.*, 2004).

There is a paucity of information in regards to the avoidance reactions by whales to the presence of vessels (Bezamat *et al.*, 2014). Experimental exposure of northern right whales to controlled sound exposure (*i.e.* vessel noise and the sounds of conspecifics), including a specifically designed alert signal, elicited a range of responses in the whales tested (Nowacek *et al.*, 2004). Exposed whales reacted mildly to the social sounds, but showed no response to the sounds of approaching vessels as well as to actual vessels. Whales reacted strongly to the alert signal by swimming to the surface, a response likely to increase rather than decrease the risk of collision (Nowacek *et al.*, 2004). Hence, ship strike mitigation strategies aimed at modifying the intrinsic behaviour of whales, which are influenced by a number of factors, such as seasonality, oceanographic features and prey availability, acting independent or in combination, will have limited utility. Conversely, modification of the operating procedures of the vessels may provide a better solution to limiting the co-occurrence of vessels and whales, reducing the risk of ship strikes.

Reducing the co-occurrence of vessels and whales

Whale stranding databases have aided in identifying a number of hot spots of whale–vessel co-occurrence, characterised by overlapping high densities of vessels and whales (Carrillo and Ritter, 2010). Therefore, identifying temporal and spatial patterns of co-occurrence between vessels and whales can inform managers (Merrick and Cole, 2007; Firestone *et al.*, 2008; Harris *et al.*, 2012) and facilitate the modelling of whale–vessel interaction probabilities (Ward-Geiger *et al.*, 2005; Williams and O'Hara, 2010; Pendleton *et al.*, 2012), which can be used to establish appropriate management strategies (*i.e.* modifying vessel routes: Fonnesbeck *et al.*, 2008).

The modification of shipping routes (both spatially and temporally) to decrease the co-occurrence of vessels and whales is regarded as the most desirable and efficient mitigation approach (Silber *et al.*, 2009; Silber *et al.*, 2012; van der Hoop *et al.*, 2012), with different rerouting measures implemented globally. Where logistically feasible and with limited impacts to shipping operations, vessel routes may be permanently or temporally modified in response to the ecological needs of the species (*i.e.* seasonal migratory behaviour and habitat use) (Conn and Silber, 2013; Mullen *et al.*, 2013; Laist *et al.*, 2014). Route modifications have largely been limited to coastal waters, where traffic routes for commercial vessels are relatively well defined and often encompass the calving grounds of many at risk species (Fonnesbeck *et al.*, 2008); hence, safeguarding the particularly vulnerable cow and calf life history stages (Ward-Geiger *et al.*, 2005; Van Waerebeek *et al.*, 2007).

Several studies have estimated that rerouting measures have the potential to reduce the risk of ship strikes by 20 to 90% (Merrick and Cole, 2007; Silber *et al.*, 2009; Vanderlaan and Taggart, 2009; Lagueux *et al.*, 2011), with differences in reduction rates specific to region and target species. Comparisons between pre- and post-implementation of vessel rerouting indicates that this mitigation strategy is successful in reducing the risk of ship strikes by up to 80% (Fig. 10) (Vanderlaan and Taggart, 2009). Critical to the successful implementation of mitigation efforts for vessel strikes is mariner compliance (Moore, 2009), with adherence to modified shipping routes showing general trends of increasing compliance over time, being as high as 96 to 100% (Vanderlaan and Taggart, 2009; Lagueux *et al.*, 2011; Silber *et al.*, 2012).

Paramount to the effective establishment of spatial and temporal management areas (*i.e.* areas to be avoided) is a sound understanding of the migration patterns and habitat use of whales (Schick *et al.*, 2009), particularly if populations of whales undergo inter-annual and seasonal variations in migratory and distribution patterns. However, as not all species of whales share the same distribution patterns (*i.e.* residential populations versus highly migratory populations), ship strike risk reduction may not be achieved simultaneously for all sympatric species (Merrick, 2005; David *et al.*, 2011; Redfern *et al.*, 2013). Moreover, rerouting shipping traffic has the potential to concentrate vessels into areas inhabited by other animals (Reeves *et al.*, 2007).

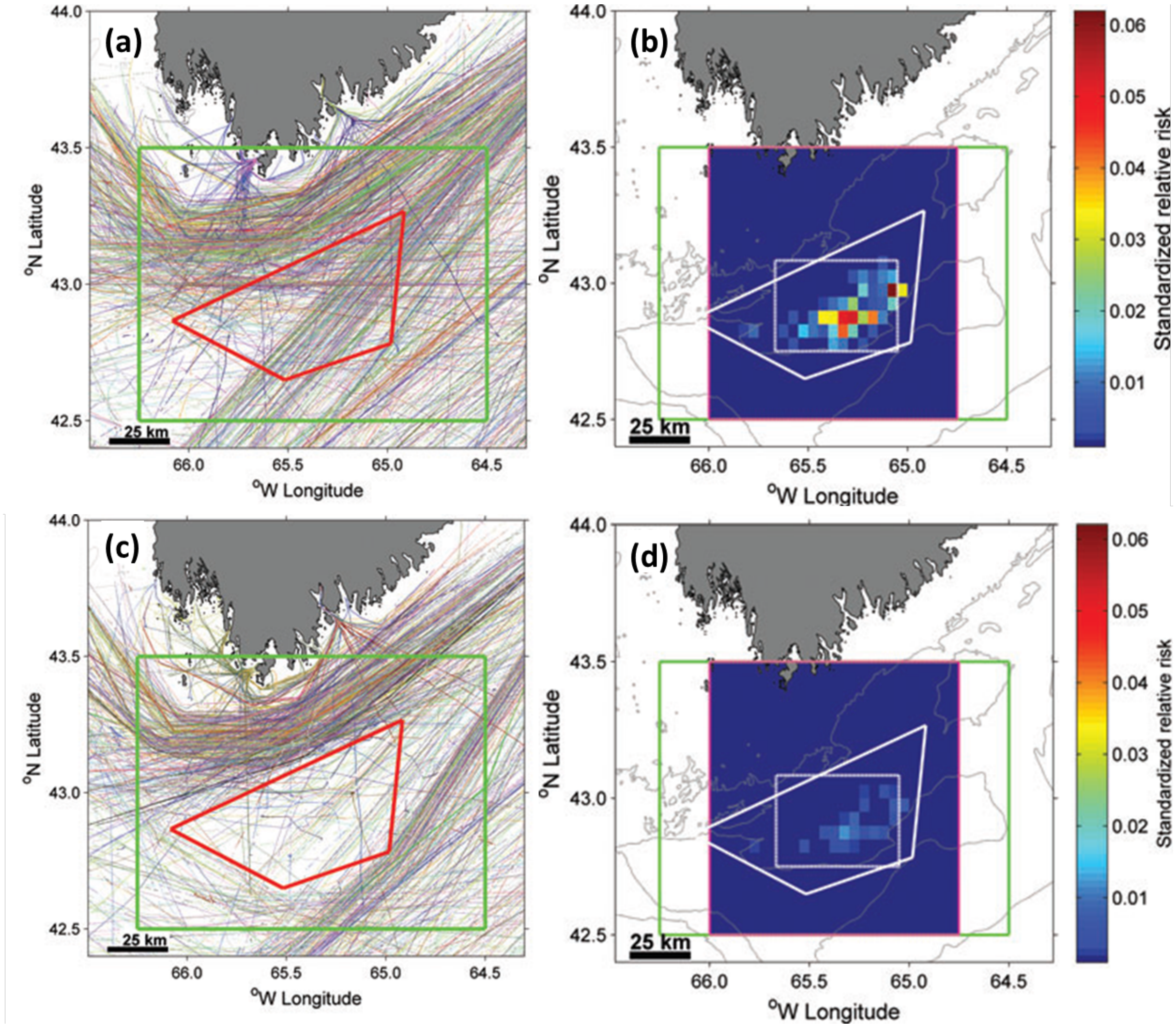


Figure 10. Modification of shipping routes on the southwest Scotian Shelf to protect northern right whales. The area to be avoided (ATBA) is shown in red in (a) and (c), or white in (b) and (d). Navigation tracks for each vessel through the region from (a) 15 June through 31 October 2007 and from (c) 1 June through 31 October 2008 prior to and following the implementation of the ATBA, respectively, and the relative risk of a lethal vessel strike to a right whale (b) before and (d) after implementation of the ATBA. Figure from Vanderlaan and Taggart (2009).

Reducing vessel speeds

All vessel types have been involved in collisions with whales, with the speed of the vessel at the time of impact directly linked to the severity of the injury the whale will sustain (Laist *et al.*, 2001; Jensen and Silber, 2004; Van Waerebeek *et al.*, 2007). The likelihood of a lethal injury is significantly higher when ships were travelling over 8.6 knots (Laist *et al.*, 2001; Clyne and Leaper, 2004; Vanderlaan and Taggart, 2007; Conn and Silber, 2013), with probabilities of mortality estimated to rise from 20 to 100% when vessel speed increased from 9 to 20 knots (Vanderlaan and Taggart, 2007). Moreover, structural damage to the vessel as a result of colliding with whales is greater when exceeding speeds of 10 knots (Jensen and Silber, 2004).

In an effort to reduce the frequency and lethality of ship strikes, while also being practical for shipping purposes, spatially and/or temporally explicit 10 knot vessel speed limits have been established around major ports and critical whale habitats (Russell *et al.*, 2001; Conn and Silber, 2013). The probability of death as a result of a ship strike was shown to decline by 50% at speeds of < 11.8 knots (Vanderlaan and Taggart, 2007). Reductions in the lethality of ship strikes at lower speeds are suggested to be due to the reduced impact of the collision and hydrodynamic forces exhorted on the whale (Vanderlaan and Taggart, 2007; Vanderlaan *et al.*, 2009; Silber *et al.*, 2010), as well as providing greater opportunity for whales and vessels to identify and avoid one another (Laist *et al.*, 2001; Gende *et al.*, 2011; Laist *et al.*, 2014).

In general mariner compliance to recommended and mandatory vessel speed restrictions have been shown to be low when initially implemented (approximately 10 to 30%); however, overtime and with the introduction of mandatory limits compliance rates increase (Lagueux *et al.*, 2011; McKenna *et al.*, 2012; Silber and Bettridge, 2012). As a ship strike mitigation measure, vessel speed limits have been estimated at effectively reducing the risk of lethal strikes by approximately 40 to 90% in some regions (Lagueux *et al.*, 2011; Conn and Silber, 2013). In addition, the numbers of and timing between ship strike induced whale strandings appear to decrease in managed regions (although these metrics are potentially confounded: Pace, 2011; Laist *et al.*, 2014).

Comparisons of the relative potential of vessel rerouting and speed restrictions for reducing probabilities of ship strikes, indicate that rerouting appears to be more effective as an independent means of reducing collision risk (by approximately 15%: Vanderlaan *et al.*, 2008; Lagueux *et al.*, 2011). When used in combination these two mitigations measures have the potential to significantly reduce the potential for ship strikes. When applied in tandem, these measures are more effective at reducing collision risk than if applied independently (*e.g.* Vanderlaan and Taggart, 2009; Lagueux *et al.*, 2011). To date, a number of countries, including Canada, France, Spain, and the United States have adopted these strategies in combination. However, in areas where rerouting is not logistically feasible, the establishment of speed limitations have been recommended (Firestone, 2009).

Several strategies have been discussed above that have been used to reduce the risk of whale–vessel collisions. Unfortunately, no one strategy will completely reduce the chances of ship strikes on whales and no single approach will fit all situations. In order to decide on potential mitigation measures, an understanding of the distribution and spatial and temporal movement patterns of whales is required in order to identify critical habitat and/or seasonal migratory pathways (Reeves *et al.*, 2007). This review has focused primarily on ship strike reduction measures adopted in waters off Canada, the United

States and in the Mediterranean Sea, areas characterised by high densities of shipping with well defined traffic patterns, but also where substantial information exists on the localised distributions of whales. However, for some species or populations of whales, for example oceanic species, there is a paucity of information on habitat use, limiting the development and/or effectiveness of some mitigation strategies. In the absence of species distributional data, the identification of preferred habitat may be estimated based on bathymetry, oceanographic conditions and productivity/prey availability (Druon *et al.*, 2012; Pendleton *et al.*, 2012). Nevertheless, there is a need for better information on the spatial and temporal distribution of many species of whales (and cetaceans more generally).

Conclusions

Interactions between vessels and whales are a global issue that for many populations of whales requires immediate action. In Australia whale populations do not appear to be as at risk to ship strikes as their Northern Hemisphere counterparts. However, the continued development of Australia's maritime infrastructure and increases in shipping capabilities suggest a need for pro-active management of vessel traffic in and around critical whale habitat, with minimal operational and economic impact to vessel operators. A better understanding of the spatial and temporal patterns of whale populations in Australia is required to aid in developing appropriate management and conservation action, as well as documenting the extent of interactions between whales and vessels.

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Appendix A

Review of EPBC Act public notices in relation to Spencer Gulf

Port Spencer export facility (Centrex Metals Limited) (approved subject to conditions)

The proposed action is to construct and operate a new deep-water private multi-user port, Port Spencer, on the east coast of Eyre Peninsula (EPBC 2012/6590). Port Spencer was declared a controlled action in late 2012 by the Commonwealth Department of SEWPAC, that would be assessed by preliminary documentation. The proposed development was given approval on 29 October 2013 subject to conditions associated with pile driving and blasting aimed at protecting southern right whales. In addition a southern right whale management plan must be developed, along with an oil spill contingency plan.

Port Bonython iron ore bulk commodities export facility (Spencer Gulf Port Link) (extension to 30 June 2015)

Spencer Gulf Port Link's proposal is to construct and operate an iron ore bulk commodities export facility near Port Bonython on Eyre Peninsula which includes a new rail line, a bulk storage facility and a 3km long jetty (EPBC 2012/6336). The project was considered a controlled action on 24 May 2012 and would be assessed by preliminary documentation. The preliminary documentation report was released for public comment in June 2013 and responses to comments provided in October 2013. Extensions to the time frame in which to make a decision whether to approve the controlled action have been made such that the latest extension is through to 30 June 2015.

Central Eyre Iron Project (Iron Road Limited) (bilateral agreement)

Two proposed actions currently exist for the Central Eyre Iron project infrastructure. One is to construct and operate an open cut iron ore mine with processing, waste management and other infrastructure near Warramboo on the central Eyre Peninsula (EPBC 2014/7349), which does not include infrastructure outside the mining lease; this proposal was not considered a controlled action (28 October 2014). The second proposal (EPBC 2014/7285) is to clear native vegetation and develop an infrastructure corridor, borefield and port facility in the central Eyre Peninsula region, which was considered a controlled action (26 August 2014). The assessment approach was to be advised. A bilateral agreement applies. The guidelines for the preparation of an EIS were released in November 2014.

Expansion of the Olympic Dam copper, uranium, gold and silver mine, processing plant and associated infrastructure (BHP Billiton Olympic Dam Corporation Pty Ltd) (approved subject to conditions)

Expansion of the existing Olympic Dam mine including all associated infrastructure was submitted on 16 August 2005, and was considered a controlled action for the purposes of the EPBC Act 1999 on 2 September 2005 (EPBC 2005/2270). As such, the project was required to undertake an Environmental Impact Statement. In the assessment report 8 EPBC listed species were identified as potentially occurring in Upper Spencer Gulf including species of whale. The infrequent presence of whales in the Gulf was noted. In October 2011 the proposed action was approved subject to conditions. Schedule 2 details the conditions regarding the construction and operation of the desalination plant at Point Lowly including the need for an environmental management action plan. Additional requirements for the desalination plant relate to salinity changes in Upper Spencer Gulf, giant Australian cuttlefish, other marine species and communities, dilution factors of the brine and further ecotoxicology testing. Schedule 3 relates to the barge landing facility and pre-assembly yard and specifically refers to not having an adverse impact on cetaceans in relation to noise or vibrations. Several variations to the conditions have been made to date (e.g. April 2013, June 2014)

Pilot desalination plant, Olympic Dam Expansion Project (BHP Billiton Olympic Dam Corporation Pty Ltd) (not a controlled action)

Proposal to construct and operate a small-scale pilot desalination plant adjacent to the Santos facility at Port Bonython (2007/3391). The proposal was submitted on 3 April 2007 and on 2 May 2007 it was not considered a controlled action.