Marine Biodiversity Hub

National Environmental Science Programme

Project C5
Quantification of risk from shipping to large marine fauna across Australia
- *Final Report*

David Peel, Joshua N. Smith, Christine Erbe,
Toby Patterson and Simon Childerhouse

Theme C - Understanding pressures on the marine environment

29rd March 2019 *Milestone 3.5 – Research Plan v3 (2017)*

CSIRO Murdoch University CETACEAN RESEARCH UNIT Curtin University Blue Planet Marine

Enquiries should be addressed to:
David Peel
David.Peel@data61.csiro.au

Joshua Smith
joshua.smith@uqconnect.edu.au

Project Leader's Distribution List

Australian Marine Mammal Centre	Mike Double Virginia Andrews-Goff
Australian Maritime Safety Authority	James Aston Matt Johnston
Consultant	Sabine Knapp
Defence Science and Technology Group	Steve Cole
Department of the Environment and Energy	
Great Barrier Reef Marine Park Authority	Mark Read
Griffith University	Susan Bengtson- Nash
International Whaling Commission	Russel Leaper
Marine Safety Queensland	Paul Brandenberg
Maritime Industry Australia Ltd	Angela Gillham
NSW National Parks and Wildlife Service	Hannah Lloyd
Parks Australia	

Preferred Citation

Peel, D., Smith, J.N., Erbe, C., Patterson, T., and Childerhouse, S. (2019). Quantification of risk from shipping to large marine fauna across Australia. Report to the National Environmental Science Program, Marine Biodiversity Hub. *CSIRO.*

Acknowledgement

This work was undertaken for the Marine Biodiversity Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Program (NESP). NESP Marine Biodiversity Hub partners include the University of Tasmania; CSIRO, Geoscience Australia, Australian Institute of Marine Science, Museum Victoria, Charles Darwin University, the University of Western Australia, Integrated Marine Observing System, NSW Office of Environment and Heritage, NSW Department of Primary Industries.

We wish to thank the following people for general advice, feedback and discussions during the project: Natalie Kelly (AAD), Paul Hedge (NESP), Nic Bax (NESP), Fiona Bartlett, Peter Benson, Sylvana Maas (DoEE), Jessica Redfern, and TJ Moore (NOAA). Furthermore, we would like to thank: Mike Double (AAD), Russel Leaper (IFAW) and Fabian Ritter (MEER) for their feedback on our collation of historical vessel strike reports. Bryony Bennet for her help with the Executive summary and various media articles during the project. Jason How (WA fisheries), Mike Double (AAD), Helene Marsh and Susan Sobtzick (JCU), Karen Arthur (DoEE), Karen Evans (CSIRO), the team at ERIN (DoEE), and Keith Hayes (CSIRO) for data and species distribution information/models. Sabine Knapp and University of Melbourne for making their projected future shipping density information available; the ERIN team (DoEE) for providing various species distribution and aggregation shapefiles; AMSA for making the AIS data available for this work (in particular Ross Henderson for earlier help) and Chris Wilcox, Jessica Ford, and Uwe Rosebrock (CSIRO) for work setting up an CSIRO AIS database; Judy Upston, Mike Fuller and Pier Dunstan (CSIRO) for their collaboration and work to produce the small recreational vessel maps, vessel registration data (de-identified) and boat ramp location data were provided by QLD Department of Transport and Main Roads, NSW Roads and Maritime Services, Transport Safety Victoria, Marine and Safety Tasmania, Department of Planning, Transport and Infrastructure South Australia, and WA Department of Transport. Finally we would like to thank all the attendees to the 2017 noise workshop for their time and useful input and feedback.

Contents

List of Figures

List of Tables

List of Assumptions

List of Conclusions/Recommendations

Appendix Figures

EXECUTIVE SUMMARY

Substantial and ongoing growth in coastal and port development, recreational boating and commercial shipping around Australia is increasing the potential for adverse interactions with marine species. This is exacerbated by growing populations of some whale species such as humpback whales.

For large marine fauna, the two major risks are vessel collisions (particularly for marine mammals and turtles) and cumulative exposure to chronic noise (across a wide range of species). Greater research focus and better methodological frameworks are needed to quantify the time and location that these risks are high, to help direct resources and monitoring toward developing and implementing appropriate management strategies.

This project combined existing data such as vessel density, speed and noise levels with species distribution/habitat models to identify Biological Important Areas (BIAs) and produce fine-scale relative spatial risk profiles. These risk profiles can be used to identify when and where marine fauna and shipping overlap, and to work through a question and answer process designed to help minimise the risk (see Table 9 in the main document). This includes evaluating relative risk, research and resourcing options, and the likely effects of management/mitigation approaches.

In future this risk assessment framework can be regularly updated as new information becomes available. For example:

- We have updated Automated information System (AIS) data annually to track larger vessel distribution (vessel traffic has increased steadily in the past three years).
- Our model and understanding of recreational vessel activity will improve following work in 2018–2019 as part of NESP project E2.
- The following new information on at-risk species is being gathered.
    - Polygons describing aggregations/range (updated BIAs).
    - New surveys/data allowing development of spatial/habitat distribution models.
    - A better understanding of behaviour (such as surface availability and/or avoidance).

The project identified five key species that were of concern and feasible to analyse. These are: **Humpback whale**, **Southern Right whale**, **Sperm whale**, **Green turtle** and **Dugongs**.

Within this report we provide an overview of the outputs from this framework as it applies to these selected marine fauna species. Underlying this is the online data (See Appendix A) that can be used to answer specific questions at particular locations and spatial scales. We also produced generic, large-whale relative risk maps based on vessel data alone.

In Section 1 we provide a table with the objective/outcomes of the Department of the Environment's National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna (2017) that this project's work feeds into and the relevant Sections.

Table 1 Summary of main species findings

Species/Population	Main Findings	Recommendations to improve risk analysis
West Coast Humpbacks (see Section 7.1)	(See Section 7.1.4 - Conclusion F) Areas identified to have higher relative risk were: • >80m AIS equipped vessels = **Dampier** to **Port headland** (Figure 32). • <80m AIS equipped vessels = **around Exmouth, Dampier, Port Headland,** & **Broome** (Figure 33) • >15kts AIS equipped vessels = **Dampier, Augusta to Perth,** & **Broome** (Figure 34). • Rec vessels = population centres **Augusta to Perth, Geraldton**, & **Broome** (Figure 35) • Of the identified humpback resting areas, **Cape Naturaliste** and **Houtman Abrolhos** appeared to have the highest relative risk (Figure 36 and Figure 37).	• Refinement of Tag movement model • Ground-truthing and validation of model against existing survey/sighting data
East Coast Humpbacks (see Section 7.2)	(See Section 7.2.6- Conclusion G) Due to different data, the analysis was split into 3 regions, Great Barrier Reef Area, Southern Queensland and New South Wales. Overall indications are that the **Great Barrier Reef** region is most likely to have the highest relative risk on the East coast (Figure 60, Figure 61) <u>Great Barrier Reef Region</u> Comparing calf groups to adult only groups: • For >80m length AIS equipped vessels, the risk to **calf groups** in the GBR region was **22.7%** more than the risk **to adult groups** (Figure 52). • For smaller <80m length AIS equipped vessels due to their more coastal/shallow water distribution, **calf groups** had **63.9%** more relative risk than **adult** only groups (Figure 52).	• Aim to build an integrated map of the whole coast. However, more data and method development will be needed. • Fill the gap in the GBR distribution model for the Capricorn/Bunker Group in the Southern GBR region.

Species/Population	Main Findings	Recommendations to improve risk analysis
	In terms of **changes** in overall risk between **2013 and 2015**: • For >80m length AIS equipped vessels, we saw **no discernible overall increase in risk** based on vessel traffic change, however, increasing humpback population numbers will mean risk will have increased (Figure 51), • For smaller <80m length AIS equipped vessels, we found an **increase in risk**, which appeared to be due to increases in traffic amount rather any changes in traffic distribution (Figure 51, Figure 52) Areas identified to have higher relative risk were: • >80m AIS equipped vessels = **shipping lanes South-East of Mackay** (Figure 53) • <80m AIS equipped vessels = **Mackay** and **Cairns** (Figure 47) • >15kts AIS equipped vessels = **Cairns, the main Shipping lanes between Townsville to Rockhampton**, and the particularly the **Whitsundays** (Figure 48) • Rec vessels = **Cairns** and **Mackay** (Figure 49) **Southern Queensland** Areas identified to have higher relative risk were: • >80m AIS equipped vessels = **North of Brisbane**, and **South-east of Mackay** (Figure 53) • <80m AIS equipped vessels = **Brisbane** (**Mackay** was also indicated however this may be an artefact of the boundary issue causing a spurious density hotspot) (Figure 54) • >15kts AIS equipped vessels = **North of Brisbane**, most of lower	• Refinement of Tag movement model • Ground-truthing and validation of model against existing survey/sighting data

Species/Population	Main Findings	Recommendations to improve risk analysis
	southeast Queensland, and the shipping lanes **South-east of Mackay**. (Figure 55). • Rec vessels = **Brisbane** (Figure 56) **New South Wales/Whole coast** Due to lack of whole coast humpback density data this particular analysis does not take into account animal density beyond restricting the analysis to the species migratory corridor. So results may not be informative. However, areas identified to have higher relative risk were: • >80m AIS equipped vessels = the **area off Port Macquarie** (Figure 57) • <80m AIS equipped vessels = **Brisbane, Gladstone**, and the **Whitsundays**. • >15kts AIS equipped vessels = Whitsundays, Brisbane/Moreton Bay Area, Port Macquarie, Northern Sydney, and Eden • Rec vessels = **Adelaide and Melbourne** (Figure 69).	• Better spatial information for NSW/TAS (e.g., animal density or improved definition of migratory corridor/resting areas)
Southern Right Whales (see Section 7.3)	(See Section 7.3.4 - Conclusion H) Due to not having animal density or abundance of coastal aggregations, the results cannot take into account differing spatial densities of the animals. However, there was some general indications of where relative risk is potentially higher both within the animals general range and based on the known aggregation areas. • >80m AIS equipped vessels = In the animals overall range: **Southern Western Australian coast** and **Bass Strait off the Victorian coast** and to a lesser extent **off the NSW coast up to Sydney** (Figure 63). For known aggregation areas: **Portland aggregation** at the far	• Better overall distributional data • Data on the spatial consistency of the aggregation areas year to year • Abundance estimation for the coastal aggregations • Fine-scale movement data in and around coastal aggregation areas

Species/Population	Main Findings	Recommendations to improve risk analysis
	left of the **Warrnambool** (Figure 64). If we also consider shipping surrounding the aggregation areas, **Augusta**, **Albany** and **Warrnambool** regions are adjacent to well used vessel routes (Figure 64). • <80m AIS equipped vessels = (Figure 66) • >15kts AIS equipped vessels = in the animals overall range: **Brisbane/Moreton Bay** and **Sydney** (Figure 68). There was little activity in or near the coastal aggregations (Figure 67) • Rec vessels = around **Adelaide and Melbourne** (Figure 69)	
Sperm Whales (see Section 7.4)	(See Section 7.4.4 - Conclusion I) Since Sperm whales have a deep-water distribution larger rather than smaller vessels are the main risk. • >80m AIS equipped vessels = Augusta **to Albany** (Figure 74). There is also a shipping lane passing through the **South Australia region**. • <80m AIS equipped vessels = **Perth region** (Figure 75). • >15kts AIS equipped vessels = little activity through all 3 regions (Figure 76). These results correspond to vessel traffic within aggregation areas, however all of the aggregations are to some extent surrounded by vessel routes/traffic which will be relevant to vessel strike risk.	• More distribution information • Relative aggregation abundances
Dugongs (see Section 7.5)	(See Section 7.5.4- Conclusion J) Due to shallow/coastal distribution and the type of collisions likely, we focused on fast moving vessels and recreational vessels.	• Improved recreational vessel models • Obtain raw density/data for dugong distribution models and expand

Species/Population	Main Findings	Recommendations to improve risk analysis
	Based on this preliminary analysis for the East coast: • >15kts AIS equipped vessels = **Far North Queensland, Gladstone** and **Moreton Bay** (See Figure 79) • Rec vessels = Very uncertain but **Hervey Bay** and **Moreton Bay** (See Figure 80).	spatially coverage with any data/models from Northern and Western Australia. • Fine-scale examination of areas of concern (For example based on maps similar to those in Appendix F).
Green Turtles (see Section 7.6)	(See Section 7.6.4 - Conclusion K) • >15kts AIS equipped vessels = **Far North Queensland**, Shipping lane offshore from **Gladstone, South-East Queensland, and Melbourne** (see Figure 82) • Rec vessels = broadscale indications were that the highest risk is in **Queensland**	• Improved recreational vessel models • Further green turtle distribution data (inclusion of newer data) and more validation of the model/distribution. • Fine-scale examination of areas of concern (For example based on maps similar to those in Appendix F).
Seagrass (see Section 8)	(See Section 8.1.4 - Conclusion L) Indications are regions of higher relative risk are **Cape York**, a small bed off **Magnetic Island**, a few beds in and around the **Whitsunday Island area, Gladstone, Moreton Bay**, a bed in **Sydney Harbour**, and in **Port Phillip bay** (Figure 84). All the higher relative risk areas were in Eastern Australia.	• Improved recreational vessel models • Updated seagrass bed maps, particularly in the identified areas of higher relative risk • Further examination of how to estimate total risk per bed, e.g. scaling to get surrounding vessels, how to handle the difference in size e.g. look at total risk or risk per square metre.

1. INTRODUCTION

In Australia, there have been substantial increases in both human population growth and coastal development as well as subsequent increases in recreational vessel use in coastal areas. Given the substantial increases in coastal/port development along the Australian coastline, and the associated rise in both recreational and commercial shipping (Bureau of Infrastructure, 2015) (and also population increases for some species), there is an increasing potential for adverse interactions with marine species. The risks associated with these activities to marine fauna include the potential for an increase in vessel collisions and for a contribution to cumulative impacts associated with underwater noise and potential disturbance and/or displacement from critical habitat.

Collisions between vessels and marine fauna are of increasing concern in many parts of the world, including in Australia. This is a result of the co-occurrence of vessels and marine fauna in ‘high risk areas’, whereby there are either high volumes of vessel traffic (i.e., shipping lanes or port areas) or conversely high numbers of animals (i.e., known critical habitat including aggregation areas for resting, feeding or breeding) (Cates, et al., 2017). This is particularly the case in coastal waters where the distribution of marine fauna including whales, dolphins, dugongs or turtles may overlap with a large number of vessels of various types and sizes. There is also increasing concern that commercial shipping contributes to a significant portion of the underwater noise generated by human activity. In 2014, the International Maritime Organization (IMO) adopted guidelines to reduce underwater noise from commercial ships which recognised that underwater radiated noise from shipping can have short-term and long-term impacts on marine life. Given the increases in anthropogenic underwater noise and the observed effects on marine life around the world (e.g., right whales in the USA and killer whales in Canada), there is an urgent need for a greater understanding of the impacts of noise within Australian waters and for guidance on measures to avoid or mitigate these impacts on marine fauna. Currently, the only government policy on noise pollution addresses the acoustic impacts on whales from seismic surveying specifically, yet little is known regarding the effects of other types of noise pollution for most marine species in Australia.

Research is needed to quantify both vessel strike and vessel noise risks in both a spatial and temporal context to better understand the magnitude of the problem and develop and implement appropriate management strategies. This project involves the use of existing shipping data (e.g., density, speed and noise levels), in parallel with distribution/habitat models for several of the most ‘at-risk’ marine species, to produce relative spatial risk profiles that can be used to identify areas and times where there is co-occurrence of marine fauna and vessel traffic. This project also provides the first steps towards mapping temporal, spatial, and spectral characteristics of ship noise from large commercial vessels (>20m in length). These maps use the distribution, density, and acoustic characteristics of large ships within Australian waters to develop first-order estimates of their contribution to ambient noise levels. The noise mapping of large ships in this project is preliminary work that will provide a proof of concept that a framework can be developed to produce a national ship noise map at both a broad and fine scale resolution with the aim of identifying potential impacts on marine fauna. A workshop was held in November 2017 to present the initial national ship noise maps, identify management priorities related to underwater noise by relevant stakeholders and to discuss the future direction and development of noise maps for Australia.

1.1 Objective and aims

The overall objective of the project is to develop spatially and temporally explicit maps of risk from vessel collision to marine fauna and also to produce maps of modelled ship noise within Australia. These maps will be used to inform management on a national scale of the relative areas of risk from vessel strike and levels of shipping noise. The results from the vessel strike risk assessment could be used to develop spatial and temporal mitigation strategies and recommendations aimed at minimising the impact to marine fauna.

The specific aims of the project are:

1. Develop spatial distribution models for marine species identified as suitable for a quantitative risk assessment where such models do not exist, and distribution data is available;

2. Process ship Automatic Identification System (AIS) data for coverage at the national level and produce maps of shipping density in Australian waters, to identify priority areas for further research (or areas where resources can be allocated to better understand or mitigate risk);

3. Develop spatially explicit, quantitative models of relative risk of vessel strike for selected species using species distribution models and shipping densities;

4. Assist in the development of a small vessel distribution model at a national level in collaboration with NESP project C1 and model vessel strike risk for smaller, coastal species such as dugong and turtles;

5. Develop a proof of concept framework for acoustic modelling of shipping noise and produce a national map of shipping noise from the AIS shipping data and source spectral data of various size/class of large ships using IMOS data; and

6. Convene a workshop to present initial national ship noise maps, identify management priorities related to underwater noise by relevant stakeholders and discuss the future direction and development of ship noise research for Australia.

1.2 The National Vessel Strike Strategy

In 2017, the Department of the Environment and Energy (DoEE) released a *National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna* (hereafter termed the 'National Vessel Strike Strategy')[1]. This NESP project aims to address elements of the Data acquisition and Data analysis components (Objectives 1 and 2 respectively) of the strategic framework of the *National Vessel Strike Strategy* (DoEE, 2017). The following tables identify the specific Actions of the Objectives in the *National Vessel Strike Strategy* and the sections in this report that directly address them.

[1] Available at: (http://www.environment.gov.au/marine/publications/national-strategy-reducing-vessel-strike-cetaceans-marine-megafauna)

Objective 1: Data acquisition – address information and knowledge gaps

Action	Outcome	Section
Identify species suitable for a risk assessment based on known distribution, conservation status, known critical habitat, vulnerability to vessel strike and feasibility	Ranked list of species	Section 2 (and see Peel et al., 2016)
For large vessels (those mandated to be fitted with Automatic Identification System (AIS) Class A), identify areas of high use in Commonwealth and state/territory waters. Examples may include international shipping lanes and ferry routes	Maps and data of high-use areas for vessels including calibrated level of use, vessel type and speeds.	Section 5.1
For all other vessels not fitted with AIS Class A, such as recreational vessels and high-speed sports vessels, identify areas of high use, including near shore locations, confined bays and boat ramps.	Preliminary maps of national relative recreational vessel density	Section 5.1.4
Collect information on vessel strike using all available records including historical records, government records (including state databases such as the New South Wales' *Elements Marine Fauna* Database and Queensland's *StrandNet*) and the DoEE *National Ship Strike Database*.	Maps and data describing reported vessel strikes.	Section 10.1 (and see Peel et al., 2018)

Objective 2: Data Analysis - determine risk of vessel strike

Action	Outcome	Section
Develop methods to determine the relative risk of vessel strike for different species at an appropriate scale (local, regional or national).	Robust methods to estimate relative risk quantitatively	Section 3 and 10.5
Undertake a national relative risk analysis for a range of marine taxa identified as suitable for analysis in the previous objective.	Maps and data of locations and species including identifying sites with a higher relative risk of vessel collisions.	Section 3.2
Identify locations where there is a higher relative risk of megafauna vessel collisions.	Maps and data of locations and species where there is a higher relative risk of megafauna vessel collisions.	Section 6

2. SPECIES SELECTION FOR RISK ANALYSIS OF VESSEL STRIKE

2.1 Method

The objective of the first phase of this project was to conduct a review of marine fauna species potentially involved in vessel strikes, and identify a subset of species for which a risk analysis could be undertaken. This was undertaken as part of *Project A2/C5 - Scoping of Potential Species for Ship Strike Risk Analysis* and is outlined in the Final Report by Peel et al. (2016). A systematic approach was used to evaluate each species in terms of Priority and Feasibility, that informed the Suitability of a species and, ultimately, the Project Order based on the following criteria:

Priority - This assessment was to provide an evaluation of species for which the national modelling of risk would be both useful from a management context (e.g., a species has a high threat status) and that vessel strike has been established as a known risk (Table 2). This included the assessment of two data elements: (a) the available evidence for vessel strike (both in Australia and internationally) and (b) the status of the species under the Australian Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and the International Union for Conservation of Nature (IUCN) Red Listing. Documented evidence of vessel strikes was scored as None, Weak and Strong evidence of occurring in Australia and a binary Yes and No for occurrence worldwide. Classification of the species conservation status was based on:

- **High** – a status of *Endangered* under the EPBC or, if assigned a lower status than Endangered under the EPBC Act but *Endangered* or *Near threatened* under IUCN;
- **Medium** – A status of *Vulnerable* under the EPBC or *Vulnerable* under the IUCN; and
- **Low** – All other status categories under the EPBC (e.g., *Not listed*, *Migratory*, *Cetacean*) and under the IUCN (e.g., *Not threatened*, *Data deficient*, *Not listed*).

Table 2 Determination of species Priority for modelling based on evidence of vessel strike and species conservation status

		Species conservation concern		
		Low	**Medium**	**High**
Vessel strike evidence	**Strong**	Low	Medium	High
	Medium	Low	Low	Medium
	None	Low	Low	Low

Feasibility - This assessment was used to indicate how practical an analysis of the species would be within the project timeframe (Table 3). The main criteria was availability of suitable distribution data that could be used to model risk for that species at a national level. In assessing the availability of species data, a previously developed data classification tier system from the USA National Oceanic and Atmospheric Administration (NOAA) to map cetacean density and distribution within USA waters was utilised for consistency. Essentially, the better the quality and availability of the data, the higher the Tier is it assigned with Tier 1 being the best and Tier 5 the worst. A further consideration was the size and types of vessels likely to be involved in vessel strikes. Currently, AIS data is easily accessible for monitoring large vessel (>20m length) movements, however a nationwide distribution of small vessels (<20m) needed to be developed.

Table 3 Calculation of Feasibility based on species distribution data and size of vessels involved in vessel strikes (colour indicates tier).

		Species Information Tier				
		5	**4**	**3**	**2**	**1**
Vessel size	**Large**	5	4	3	2	1
	Small	3	3	3	4	5

Once Priority and Feasibility had been assessed, these were then combined to determine overall **Suitability** for national modelling of the risk of vessel strike (Table 4), based specifically on whether:

a) Vessel strike is likely to be having an appreciable impact;

b) There is existing substantial information on species distribution and abundance, as well as other behavioural aspects, such as migration patterns, breeding cycles; and

c) The species is listed under the EPBC Act as vulnerable, endangered or critically endangered.

Table 4 Species Suitability ranking matrix used for prioritising species involved in vessel strike risk assessment

		Feasibility				
		5	**4**	**3**	**2**	**1**
Priority	**High**	C	B	A	A+	A++
	Med	C	B	A	A+	A+
	Low	C	C	B	A	A

These preferred species were then allocated a **Project Order** to (a) determine which would be done and (b) in which order in the work plan. This overall ranking therefore represents a balance between species status, a species' distribution data quality and availability, vessel strike risk, and overall achievability. A full table of all species considered is given in Appendix B and a summary of final key species shown here in Table 5.

Table 5 Summary of the prioritisation of species to be included for national modelling of the risk of vessel strike

	Priority			Feasibility				
Species	Vessel strike Evidence	EPBC/IUCN Status	**Priority**	Species Distribution Information	Vessel size data needed	**Feasibility**	**Suitability**	**Project Order**
Humpback whale	Strong	M	Med	3	Large	3	A	Phase 1
Pygmy blue whale	Strong	H	High	4	Large	4	B	
Southern right whale	Strong	H	High	3	Large	3	A	Phase 1
Sperm whale	Strong	M	Med	4	Large	4	B	
Australian snubfin dolphin	Strong	H	High	4	Small	4	B	Phase 3
Australian humpback dolphin	Strong	H	High	4	Small	4	B	Phase 3
Dugong	Strong	L	Low	3	Small	3	B	Phase 2
Green turtle	Strong	H	High	4	Small	4	B	Phase 3
Leatherback turtle	Strong	H	High	4	Small	4	B	

2.2 Conclusions/Summary

Conclusion A Species that are currently suitable for analysis in the project

Based on the Suitability index, **humpback** (*Megaptera novaeangliae*) and **Southern right** (*Eubalena australis*) whales were priority candidates for analysis, followed by **dugongs** (*Dugong dugon*), **green turtle** (*Chelonia mydas*), Australian snubfin dolphin (*Orcaella heinsohni*) and Indo-Pacific humpback dolphin (*Sousa sahulensis*) (see Table 5).

Initially, the development of species distribution models for snubfin and humpback dolphins was being undertaken by other research groups. However, neither of these projects eventuated and therefore these species were unable to be included in this vessel strike risk assessment project.

Based on the lack of data for these two species, it was decided to include **sperm whales** (*Physeter macrocephalus*) instead, predominantly due to their conservation concern as indicated by their potential lack of recovery from commercial whaling.

3. RISK ASSESSMENT FRAMEWORK

This section provides a general overview of the risk framework used in the project and some key aspects of its interpretation.

3.1 Relative versus Absolute risk

As referred to in the National Vessel Strike Strategy (DoEE 2017) there are two types of vessel strike risk: relative and absolute risk.

"Relative risk can predict where a collision is more likely to occur, but not how many collisions are likely to occur. As such, relative risk will not provide an indication of the magnitude of the risk, but rather a measure that compares risk between different areas. For example relative risk may indicate that the risk of collision is higher in area A than area B, or the risk of collision is 2.5 times higher in area A than area B.
Absolute risk quantifies the actual probability of a collision occurring in a defined geographical area. For example, area A has a 20 per cent chance of an individual and a vessel colliding in a given timeframe." (DoEE 2017)

The risk metric discussed in this project is relative risk which, does not give any indication of the true frequency of collisions but rather provides a unit-less measure that can be used to compare risk. Specifically, we also aim to estimate a probability that is proportional to the true expected probability of fatal vessel strike. This allows us to ignore terms/aspects that are unknown but reasonably constant across cells, while still allowing a relative comparison of risk between spatial locations and other comparisons.

The reason for the decision to use relative risk was:

- For most of our species there are many unknown parameters such as surface availability, response/avoidance of vessels, etc. (see Appendix E);
- Even when there is some information on the required parameters the amount of uncertainty/variance on these parameters is generally unknown;
- There is uncertainty/variance on the parameters and modelling of animal distributions that, if propagated, would likely indicate that the uncertainty around any absolute numbers is large making them essentially meaningless;
- There may be unknown mechanisms/processes involved that have not been modelled such as blunt force impacts versus propeller interaction (see Appendix E); and
- There is a likely issue with the assumption of independence used in all existing methods aimed at providing absolute risk. It is currently assumed for the animal distribution values within the absolute risk assessment, that animal density can be replenished whereas it is more appropriate that individual animals will not be replaced if removed. This is a complex issue that requires further discussion and peer review.

However, it potentially makes risk measures negatively biased in locations where there are high densities of vessels.

The decision to interpret all results as relative risk measures simplifies the calculations in that any parameter that is constant across the population can be ignored, even if unknown. For example, if the amount of avoidance behaviour is unknown but is assumed to be the same between spatial areas, then the relative risk between the two areas can be compared without including avoidance probability in the formulation. This means that relative risk can still be an excellent tool for exploring and quantifying relative risk across large spatial areas and scales.

Further work and information on key parameters for each species would be required for absolute estimates of risk. These include information on:

- Surface susceptibility of species. This will depend on the species dive behaviour and the vessels draft and disturbances caused by propeller motion.
- Responsive behaviour of species to vessels both in close proximity and more general avoidance/attraction to areas of high density of vessel activity.
- Accurate speed versus probability of death models/curves
- More precise species distribution models

The relative risk maps could provide information on where best to conduct research to collect this information.

Some of the benefits of ultimately developing absolute risk measures would be:

- A better understanding of the magnitude of the problem
- The ability to estimate population impacts
- The possibility of comparing the risks of different species

3.2 Risk Metrics

The risk measures used in this project required two types of information: Vessel data (see Section 5) and Animal data (see Section 4).

The project uses three versions of relative risk depending on the available data and application (**Figure 1**). The three different approaches show increases in complexity depending on increasing amount of data and are described in more detail below.

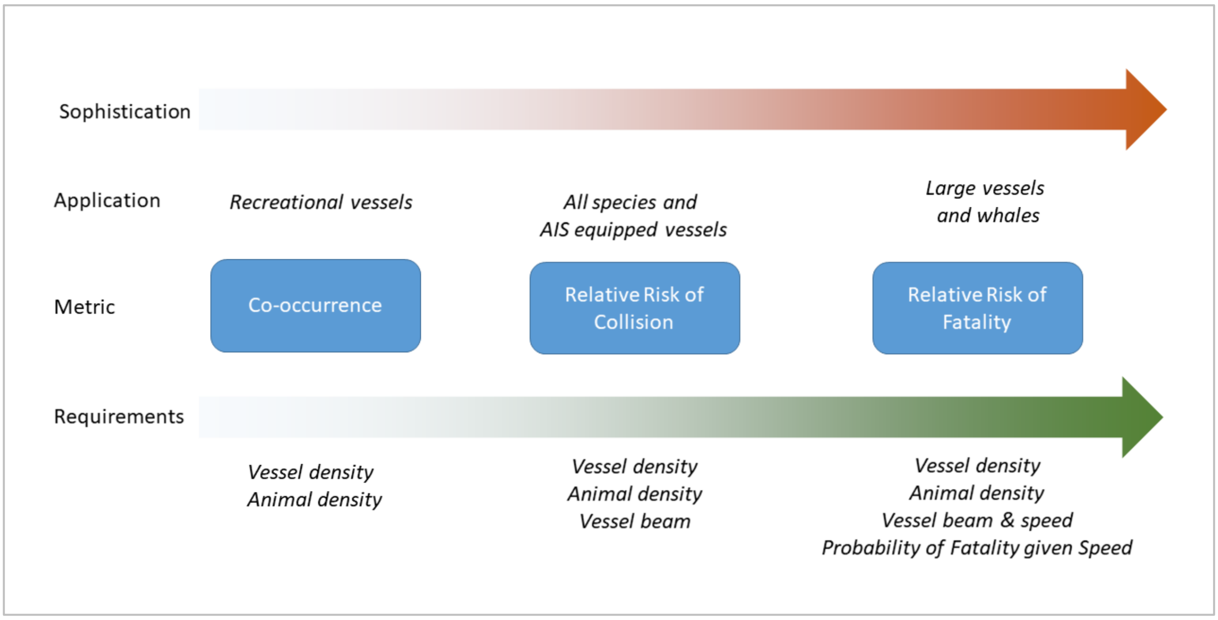


Figure 1 Summary of risk metrics used in the project

3.2.1 Relative Risk of a Fatal Collision

Several researchers have proposed more complex risk metrics than co-occurrence (e.g., Tregenza et al. (2000), Van Der Hoop et al. (2012), Peel et al. (2015), and Martin et al (2016)). These approaches generally aim to estimate absolute risk. However, for the reasons outlined in Section 3.1, we believe achieving a useable absolute probability of fatal vessel strike is extremely difficult in most applications, and in some cases would be unwise. Therefore, we prefer to consider the more complex risk metrics as more refined relative measures of risk (see Section 3.1) that better mimic reality and include the other aspects/parameters that can change the relative risk.

The method used in this project was described in Peel et al. (2015) and formulates a relative probability of a fatal strike occurring. Independently, at the same time a very similar framework was proposed by Martin et al (2016).

For full detail see Peel et al. (2015) but in summary we break down the event of a fatal collision into its component parts - that for a fatal collision to occur there must be a collision and the injury must be fatal. Let us consider a single grid cell, in general terms we can think for a given whale, *w,* the probability of a fatal strike from a single vessel, *v,* as the probability of a fatality given there was a strike multiplied by the probability there was a strike, using a conditional probability rule

$$\Pr(Fatality_{w,v}) = Pr(Fatality_{w,v} | Speed_v, Strike_{w,v}) \times Pr(Strike_{w,v})$$

The $Pr(Strike_{w,v})$ can be further broken down into the probability the animal is close enough to the surface to collide or be pulled into the propeller; the probability the animal and vessel are in the same location, and the probability the animal does not avoid the vessel. That is,

$$\Pr(Strike) = \Pr(\text{Depth}_w \leq \text{Draft}_v) \times \Pr(xy_w = xy_v) \times (1 - \Pr(Avoidance_w | Speed_v))$$

For some species such as large whales there is some information on the $Pr(Fatality_{w,v} | Speed_v, Strike_{w,v})$. For example, see Vanderlaan and Taggart (2006). However, in most other species, this relationship is unknown as we do not have any information on probability of fatality given speed. In these cases, we propose to simply consider at the risk of a collision (See Section 3.2.2).

3.2.2 Relative Risk of a Collision

For this project, for all species except large whales, we do not have any information on probability of fatality given vessel speed. For these cases we removed the $Pr(Fatality_{w,v} | Speed_v, Strike_{w,v})$ term from the calculation. This basically means we are calculating the relative risk of any collision occurring rather than the relative risk of a fatal collision. Generally, for management this may be equally as important, when animal health and welfare are considerations.

3.2.3 Co-occurrence Risk

The first metric implemented was a simple measure of co-occurrence, which assuming other variables are constant spatially, should be roughly proportional to risk. The measure of co-occurrence in a particular grid cell (*i,j*) on a map, was simply taken to be the distance traversed in a cell by ships D_{ij}, multiplied by the number of whales in the cell W_{ij},

$$\text{Risk}_{i,j} = D_{i,j} \times W_{i,j}$$

Examples of the use of a co-occurrence type approach are Fonnesbeck et al. (2008), Vanderlaan et al. (2008), Bauduin et al. (2013), Redfern et al. (2013), and Peel et al. (2015).

This is particularly useful when there is a lack of information required to use the more complicated models of Section 3.2.1 and Section 3.2.2

3.2.4 Assumptions and caveats

All of the risk metrics used in this report make the same underlying assumptions given in Assumptions 1. Furthermore, the three risk metrics each has its own specific assumptions given in Assumptions 2 to Assumptions 4

Assumptions 1 General assumptions and caveats for various risk metrics

- That the risk increases linearly with density of vessels and animals.
- The various parameters that can possibly affect the risk of a collision are constant spatially and across the population age groups. Examples include:
  - animal avoidance/attraction behaviour; and
  - surface availability.
- All vessels have the same risk of collision (i.e., the design or type of vessel does not drastically affect the risk of a collision). This is potentially untrue, however without specific information/data, we must make this assumption.

Assumptions 2 Assumptions and caveats for <u>co-occurrence risk metric</u>

- All of Assumptions 1
- That the risk is proportional to the density of vessels and animals
- The risk metric does not take into account vessel size and speed or other parameters that may affect risk of collision

Assumptions 3 Assumptions and caveats for <u>relative risk of collision risk metric</u>

- All of Assumptions 1
- In all of our applications we have little information on biological parameters that may affect vessel strike risk (e.g., avoidance behaviour, surface availability). These are assumed to be an unknown constant or, where there is information, as a known constant. Since we are estimating relative risk, this is not an issue unless the parameter is not constant spatially, temporally or within the population.
- Since we do not have much information on some of the parameters and even less is known about their variability at this stage, it is difficult to propagate error and provide a robust measure of uncertainty/error on the final risk measures.

Assumptions 4 Assumptions and caveats for <u>relative risk of fatal collision metric</u>

- All of Assumptions 1 and Assumptions 3
- The probability of fatality given vessel speed we use (e.g., Conn and Silber (2013) for large whales) is correct and applicable to the species in question.

The risk measures used in this project require two types of information: Vessel data (see Section 5) and Animal distribution data (see Section 4).

3.3 Risk Mapping

3.3.1 Risk units

The relative risk mapped in this report is unit-less. As described in Section 3.1 the relative risk value has no meaning but when compared it does. With this in mind within this report generally all the vessel strike risk maps are standardised and what is being shown is a proportion of the total risk for the map in each grid cell. This gives some meaning to the risk value, e.g., a value of 10% means that 10% of the total risk for the map is in that grid cell. This makes comparisons within each map easy, but does not allow comparison across maps. Specifically, relative risk values presented on one map cannot be directly compared to another map. If this is required for a particular question maps for that purpose can be produced.

3.3.2 Spatial Scales

The risk framework/code developed in the project can produce maps at any specified resolution and projection. However, it should be noted that even though we are able to estimate risk at a very fine-scale, it is not always advisable given:

- The two components in the risk calculation (vessel density and animal density) may have differing underlying maximum resolution and the maximum resolution should be at the worst resolution of the two components. For example, the AIS vessel density data may be at a very fine scale, but often the animal density resolution is not; and
- There is uncertainty in both the vessel density and more so the animal densities. At broader scales, this will be less of an issue than at extremely fine scales.

Fine-scale maps can be produced (for example Figure 2 and Appendix F), however, it should be noted that the maps should be regarded as indicative of the spatial pattern rather than a precise measure. There will be interpolation errors especially for curved vessel paths, which will be most evident around land and islands.

In this report we present maps at two spatial scales; broad scale (usually grid cells of 0.5° longitude/latitude) to decide on general areas of higher risk and fine scale (1/30° longitude/latitude) to investigate why the area is of higher risk.

It is important to note the analysis is always done at the fine scale grid size then risk up-scaled to the broader scale. This is to avoid the issue of vessels and animals that are not near each other being classed as co-occurring and contributing to risk.

The rationale for this approach is that mapping the risk at the fine scale over large spatial areas can be misleading when trying to determine general areas of higher relative risk. For example, consider two hypothetical locations: In the first, there is a tightly defined shipping lane of medium number of vessels and in the second, a widely dispersed undefined shipping lane with many more vessels. Using a fine scale grid size map would generally indicate that the first location as high risk, whereas the second location with more vessels will show as low risk.

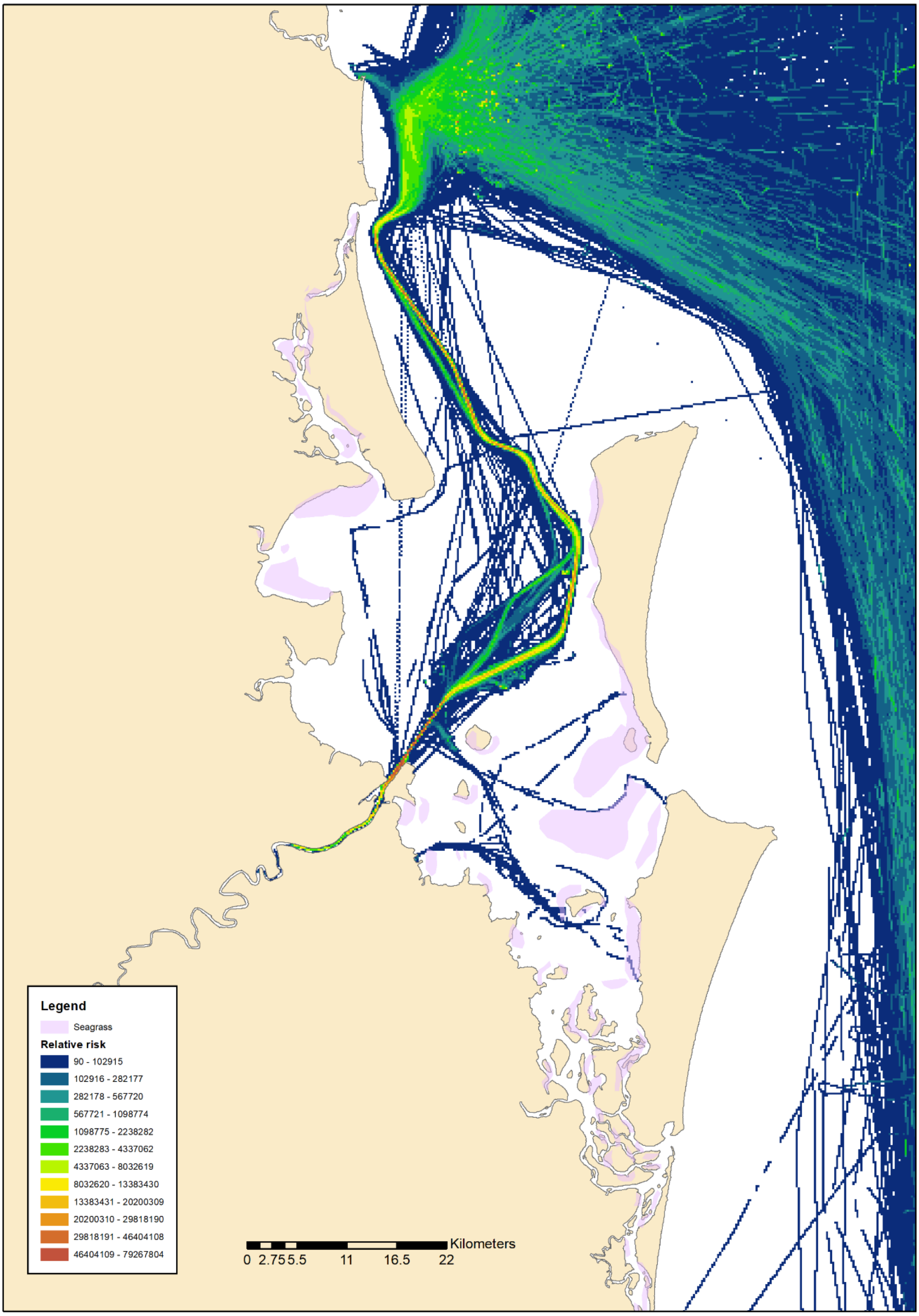


Figure 2 Example of fine scale mapping (0.02°) of data from large (>50m) AIS equipped vessels for 2015 with seagrass beds shown for their relevance to Dugongs.

3.3.3 Colour classification/mapping

To better distinguish highest relative risk, we use equal interval colour mapping on the broad scale maps. Then to better see spatial patterns of risk, we used natural breaks (i.e., Jenks) on the fine scale focused maps (see Figure 3).

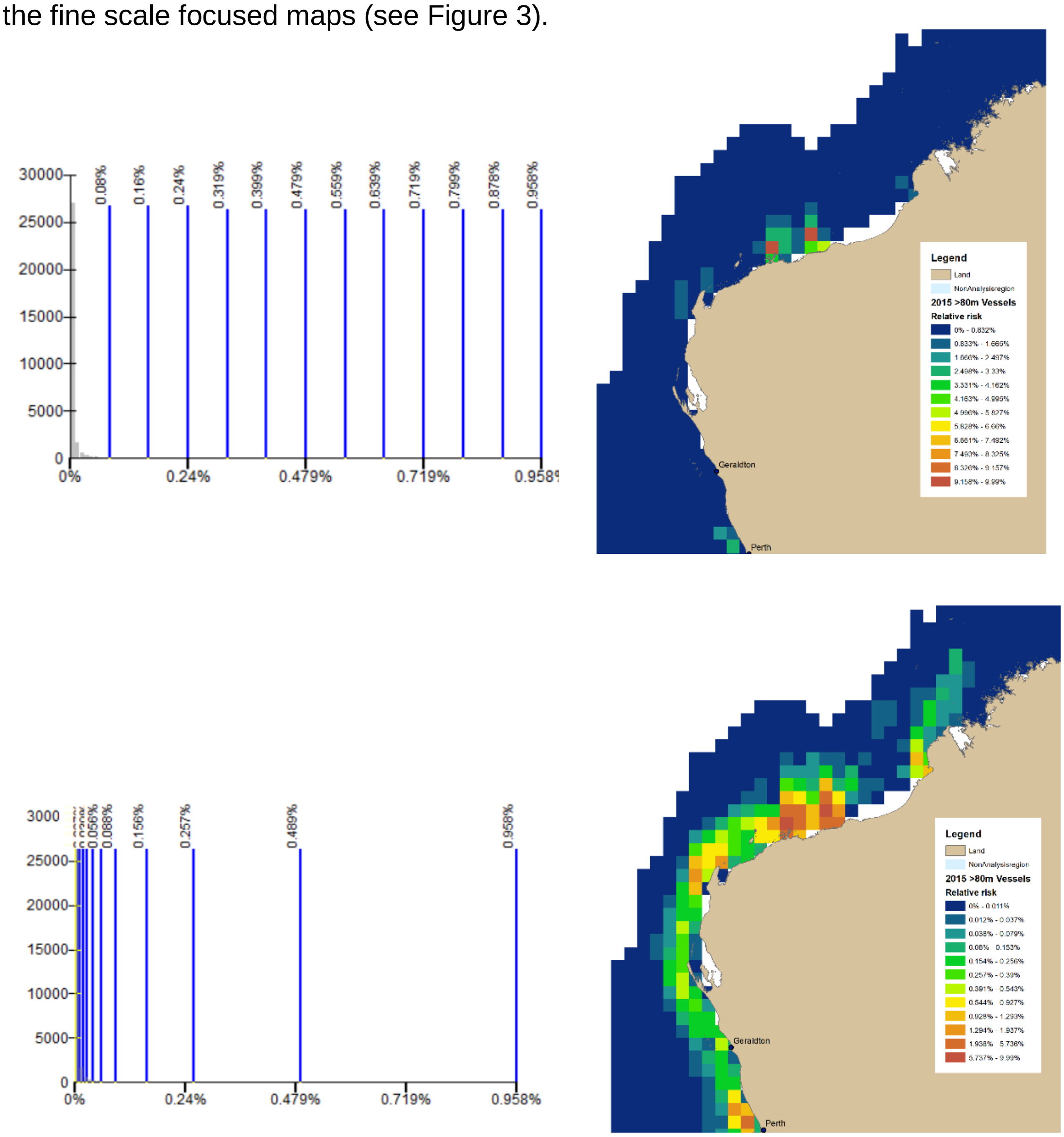


Figure 3 Examples of equal interval (top) and natural breaks (Jenks) (bottom)

3.3.4 Projections

For ease, all maps use the World Geodetic Coordinate System[2]. However, if a grid system based on a different projection is required, then these can easily be supplied.

[2] On larger scales there may be some distortion however all risk calculations are grid-cell area standardised

3.4 Conclusion/Summary

Conclusion B Summary and key ideas of risk metrics

- Risk measures for vessel strike require vessel density and some information on animal distribution.

- Depending on the species and distribution information, we use 3 variations of risk in order of preference:

  1) **Relative risk of a fatal collision** – Only used for large whales and all vessels>80m using the probability of fatality given speed model from Vanderlaan and Taggart (2006).

  2) **Relative risk of collision** – For non-large whales and also the maps of smaller vessels (<80m length) and Fast moving vessels of any size (>15kts) the Vanderlaan and Taggart (2006) model is unlikely to be applicable so we mapped relative risk of collision for except for recreational vessels.

  3) **Co-occurrence risk** – For non-AIS vessels (e.g. small recreational vessels) we used the simpler co-occurrence risk metrics in maps.

- In essence, relative risk of collision could be thought of as an extension of co-occurrence risk that takes into account vessel beam and if information is available can incorporate other parameters such as surfacing behaviour. Relative risk of a fatal collision is simply relative risk of collision with the probability of fatality given vessel speed included in the calculation.

- We **recommend** using this kind of absolute formulation of risk (i.e., including any parameters and mechanisms that are known) but interpreting and using the result as a relative risk measure.

- We **recommend** when looking at overall risk on large spatial scales to use a larger grid size to identify areas of higher risk and then, for those high risk areas, to use a small fine scale grid for improved resolution.

- We **recommend** when looking for areas of highest risk, use equal interval colour mapping. However, when looking for general patterns and distribution, use a colour map that reduces the weighting of extreme and/or high values, such as natural breaks (i.e., Jenks).

4. ANIMAL DATA/MODELS

4.1 Spatial/Habitat model

The best animal information for the risk analysis is a complete map of animal density for the full range of the species. For the purposes of this work, a spatial/habitat model-based map is simply any map that gives an estimate of animal density or some similar measure at any specific location.

We are not necessarily concerned with how this map was derived (e.g., line transect surveys, presence-absence data, presence only data) except to understand how this may influence the assumptions, limitations and biases of the resulting map.

4.2 Tag movement tracking model

Another form of data that is collected on some of the species of interest is movement data from tagging. The issue with using this data directly is:

1. It provides detailed information on individuals and may not give a full representation of the whole populations; and

2. The locations provided by the movement data are highly correlated in time and the data cannot be used directly to produce density maps.

To address issue 2, as part of this project, we developed a new method to interpolate/model movement data and produce density maps. In summary, the method fits a spatial model on direction travelled in each cell to produce a probabilistic flow mapping. From this flow map, data can be simulated. Further information on this method will be provided in Peel et al. (In prep).

4.3 Polygon aggregations/range

For species where we did not have a density map but only have polygons describing animal aggregations/range, we assumed uniform distribution and density within the polygons. For example, some of these data were sourced from species recovery plans (Department of Sustainability, Environment, Water, Population and Communities, 2012) or Biological Important Areas (Department of Environment and Energy 2015).

4.4 Assumptions and caveats

Assumptions 5 Assumptions and caveats for spatial habitat modelling and their use in the project

- Each method/approach will have some unique issues/caveats depending on the type of data the model was built on and its inherent analysis methodology. Therefore, we will report specific caveats/assumptions about the data sources in each species section. However, generally:
  - The models are often snapshots in time and may not capture the temporal changes and/or uncertainty outside of the actual survey period. For example, a model based on a single survey year will not capture any year to year changes in distribution. Similarly, a short survey may not capture within season changes/movement;
  - Most of the models produce relative indices of abundance as part of the distribution maps. This is due to a number of reasons but the main one is predominantly that the detection probability (e.g., sightability, surface availability, observer bias, probability of discovering a stranding, etc.) is not able to be completely quantified; and
  - It is assumed that the data/models completely cover the entire population range. For example, there are no unknown high-density areas outside the survey/model range.

Assumptions 6 Assumptions and caveats for tag movement model

- That the sub-set of tagged animals is representative of the whole population.
- That movement is Markovian like. That is, in a grid cell, where the animal goes next does not depend on where the animal has previously been. An example of when this assumption would not hold is if there were two types of animals passing through a particular grid cell: those that had previously travelled offshore, and those that had previously travelled inshore and the two types of animals predominantly headed in different directions out of our grid cell. However, although this will mean individual simulated tracks will not be realistic (as animals will switch randomly between the two groups at our grid cell), the overall density map produced will still be correct.
- At very fine-scales, the tag model cannot completely reproduce tight or localised shifts in animal path.

Assumptions 7 Assumptions and caveats for polygon/aggregation model

- Uniform density of animals within the polygons.
- That the polygons/ranges provided are a reasonable approximation of the animals' true range.

4.5 Conclusion/Summary

Conclusion C Summary and key ideas animal information for risk metrics

- Broadly speaking, we have 3 classes of information on animal distribution. In order of usefulness/preference:
    1) Spatial/habitat model;
    2) Tag movement model; and
    3) Polygon aggregation/range.
- There is a difficulty in practice when trying to assess distribution at the national scale where we have varying classes of information from different areas.
- As part of this report, we will aim to identify information gaps and/or where areas of animal distribution data is required to improve a vessel strike risk assessment.
- We developed a new novel method to analyse tag movement data for use in applications such as this to interpolate the tag information to provide spatial distributions (Peel et al. in prep).

5. VESSEL DENSITY INFORMATION

This section contains vessel density maps used in the project

5.1 AIS Equipped vessels

The Automatic Identification System (AIS) regularly records equipped vessels' locations and other information. There are two types of AIS, Class A and Class B:

Class A – Vessels covered by the International Convention for the Safety of Life at Sea (SOLAS)

- Vessels ≥ 300 gross tonnage engaged on international voyages
- Vessels ≥ 500 gross tonnage engaged on domestic voyages
- All commercial passenger vessels of any size

Class B – Non SOLAS vessels

- For example, domestic commercial vessels and pleasure craft

For more detail see
www.amsa.gov.au/safety-navigation/navigation-systems/about-automatic-identification-system

All the analysis described in this report used both types. The large Class A vessel coverage is comprehensive whereas for the smaller non-SOLAS craft of Class B coverage is not complete since installing AIS is voluntary.

For this project, AIS data was obtained from AMSA for 2013-2015 in the form of their craft tracking system (CTS) product. The CTS provides cleaned, processed data[3] sampled to a minimum[4] 5-minute polling frequency. This sample rate represents a good compromise between data set size and spatial uncertainty due to unknown path/locations between polling[5].

The AIS data is the polled location of a ship at a particular time and is therefore point data that is time based. It should be noted that the vessel-strike risk framework requires the distance-traversed by a vessel in a grid cell. So, we needed to convert or weight the data to distance rather than time. The ocean noise model (see Section 9) requires time spent in a grid cell, since polling rates can be irregular some processing and/or interpolation was still required.

[3] In the raw data, the AIS system can produce multiple entries for a single location from various satellites etc.
[4] Depending on location, equipment and vessel density polling rates may vary considerably
[5] Given a typical average/mean vessel speed of ~12 knots, the distance traversed in 5 mins would equate to ~1.852 km

Table 6 provides a summary of all the different AIS data subsets considered during the development of risk models with associated Figures for each model. Figure 5 provides a summary of the total km travelled for each vessel length classes for 2013-2015.

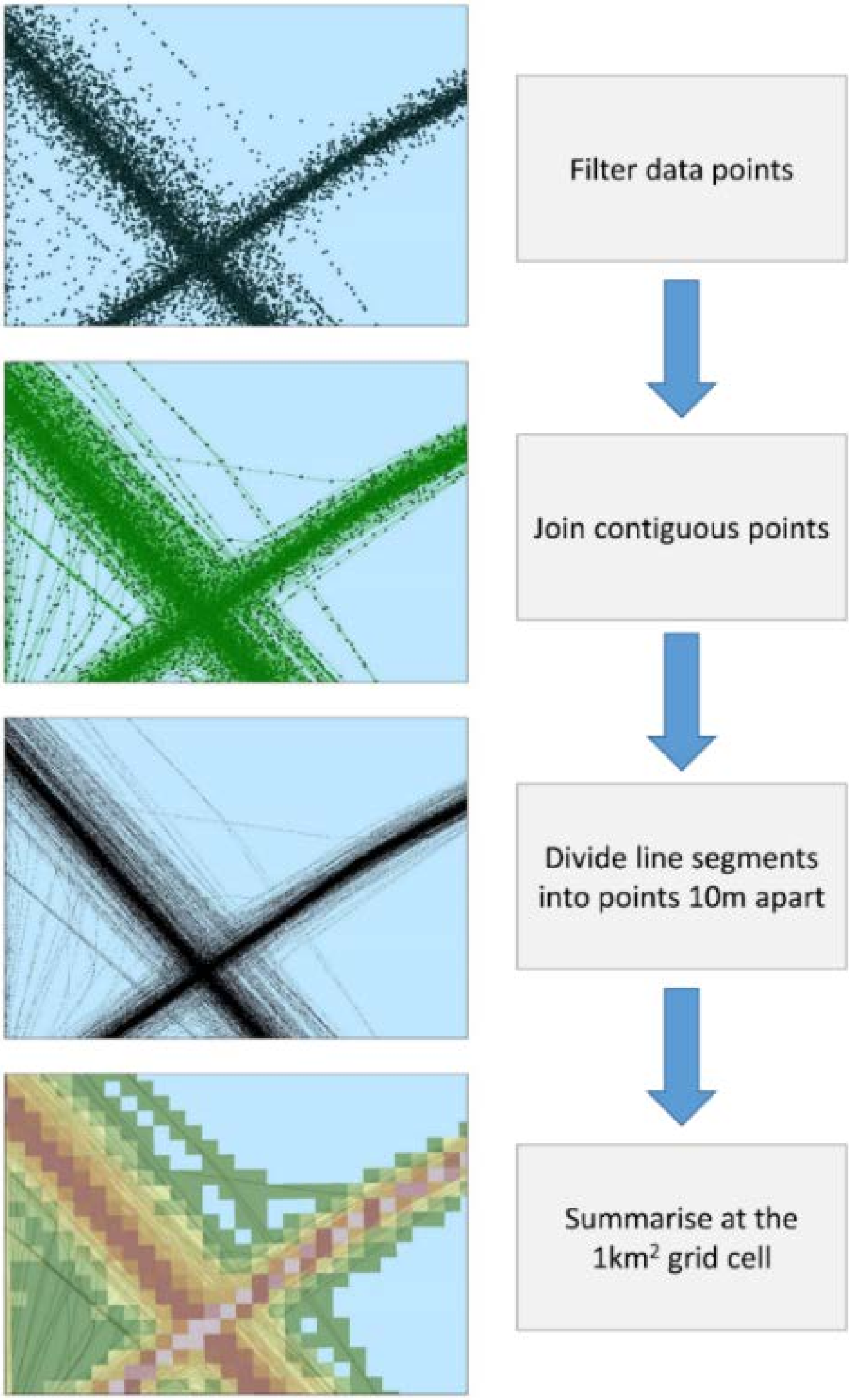


Figure 4 Example of the AIS data processing

Table 6 Summary of different AIS data subsets considered

Type	Details	Figure
Large vessels	≥80m of length	Figure 6
Small vessels	<80m length	Figure 7
Specific size classes	<10m length	Figure 8
	10-25m length	Figure 9
	25-50m length	Figure 10
	50-100m length	Figure 11
	100-200m length	Figure 12
	>200m length	Figure 13
Vessel types	Cargo	Figure 15
	Fishing	Figure 16
	Harbour (e.g., tugs, pilot vessels)	Figure 17
	Military	Figure 18
	Official	Figure 19
	Passenger (e.g., ferries, cruise ships)	Figure 20
	Recreational	Figure 21
	Sailing vessels	Figure 22
	Tanker	Figure 23
	Working vessels (e.g., offshore supply vessels, dredgers)	Figure 24
Fast vessels	Travelling >15kts speed	Figure 25
Fast moving ferries	Passenger/ferry travelling >15kts speed	Figure 26

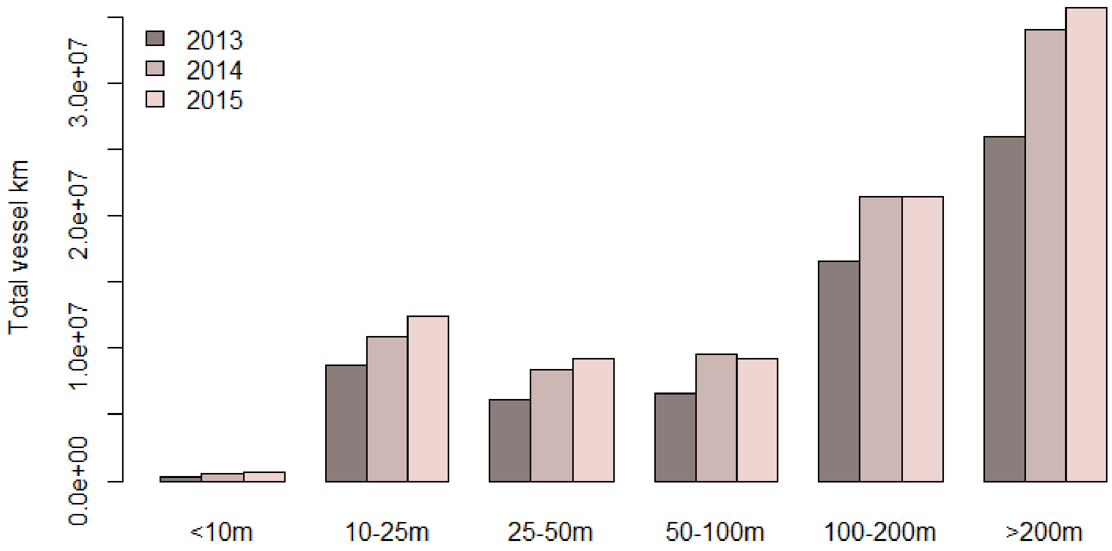


Figure 5 Summary of total vessel travel in km for various vessel length classes for 2013-2015

5.1.1 Maps of vessel density for various size AIS equipped vessels

This section provides model outputs for the various different vessel categories identified in Table 6. We have data processed for 2013-2015, however, for brevity, maps presented here are for the most recent year (2015) only.

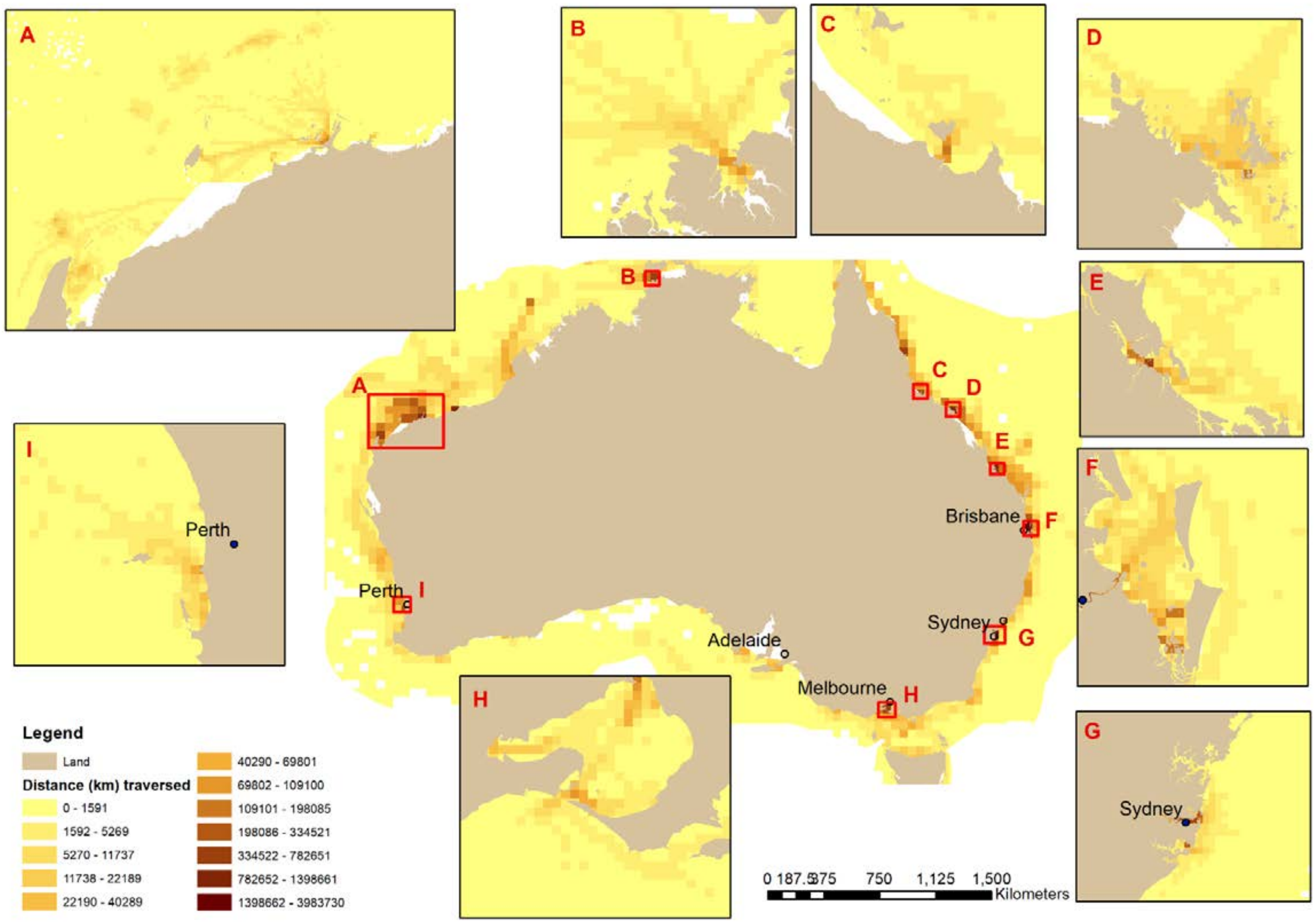


Figure 6 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length <80m, and example areas (1/30°) of higher density.

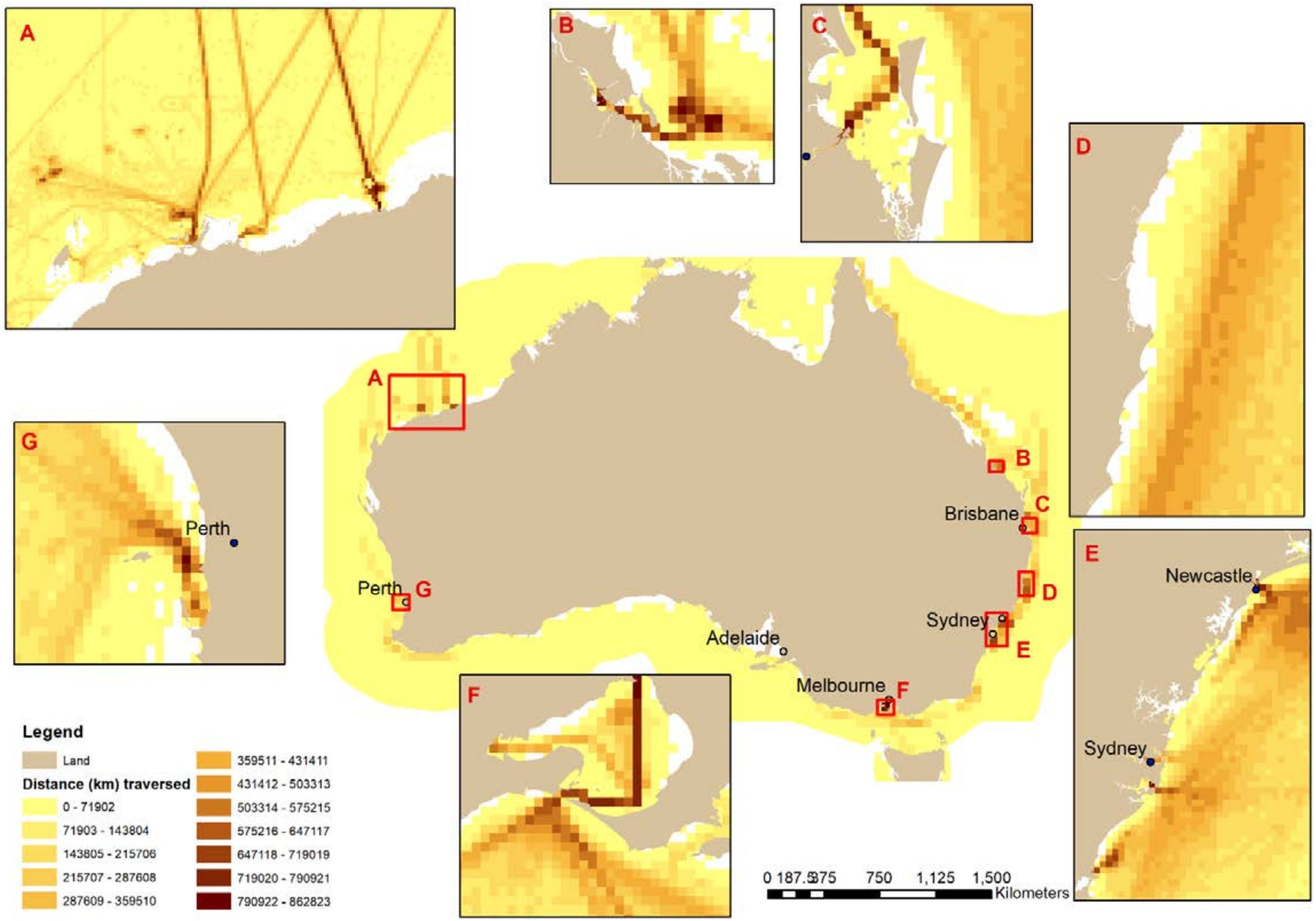


Figure 7 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length >80m, and example areas (1/30°) of higher density.

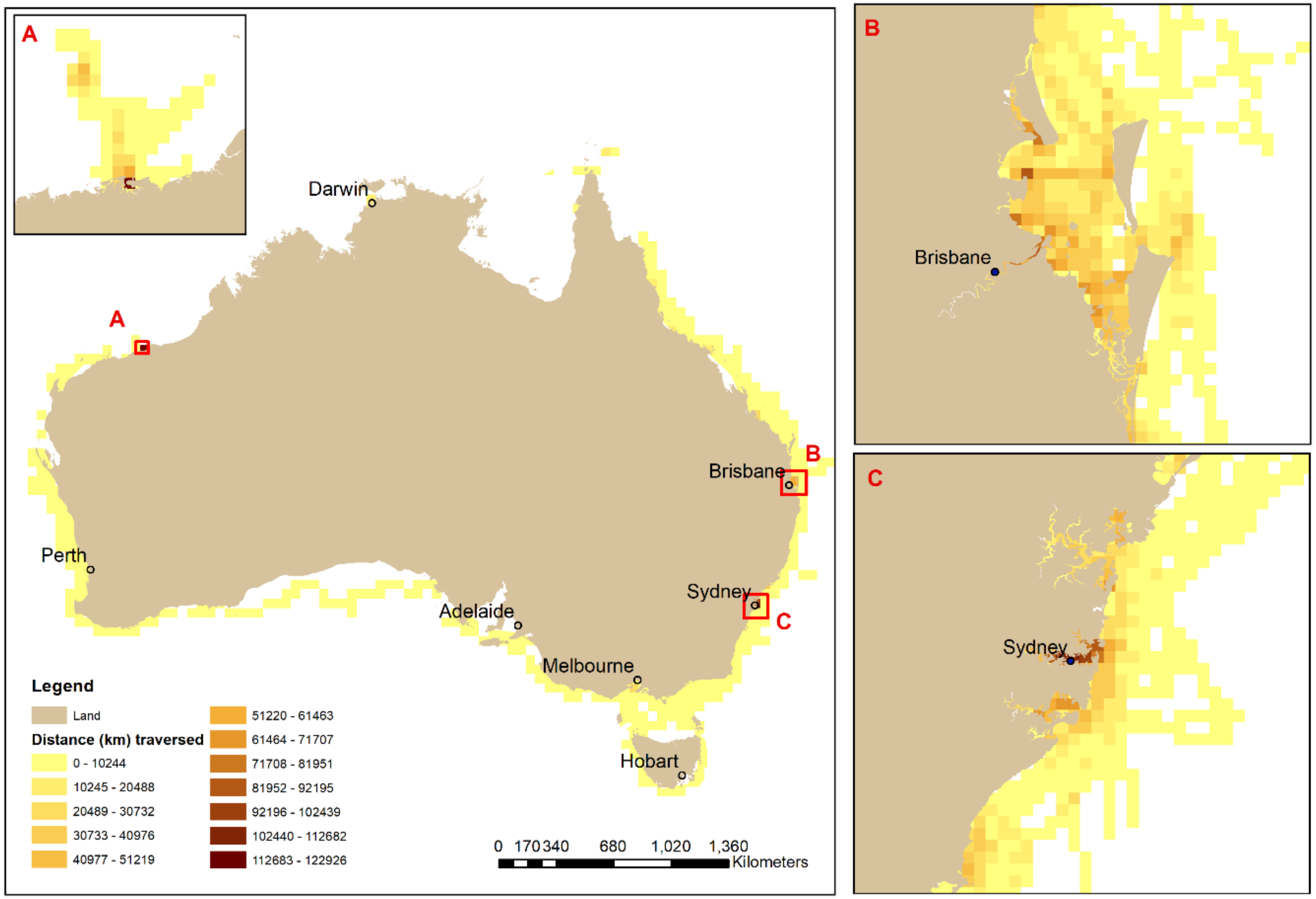


Figure 8 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length <10m, and example areas (1/30°) of higher density.

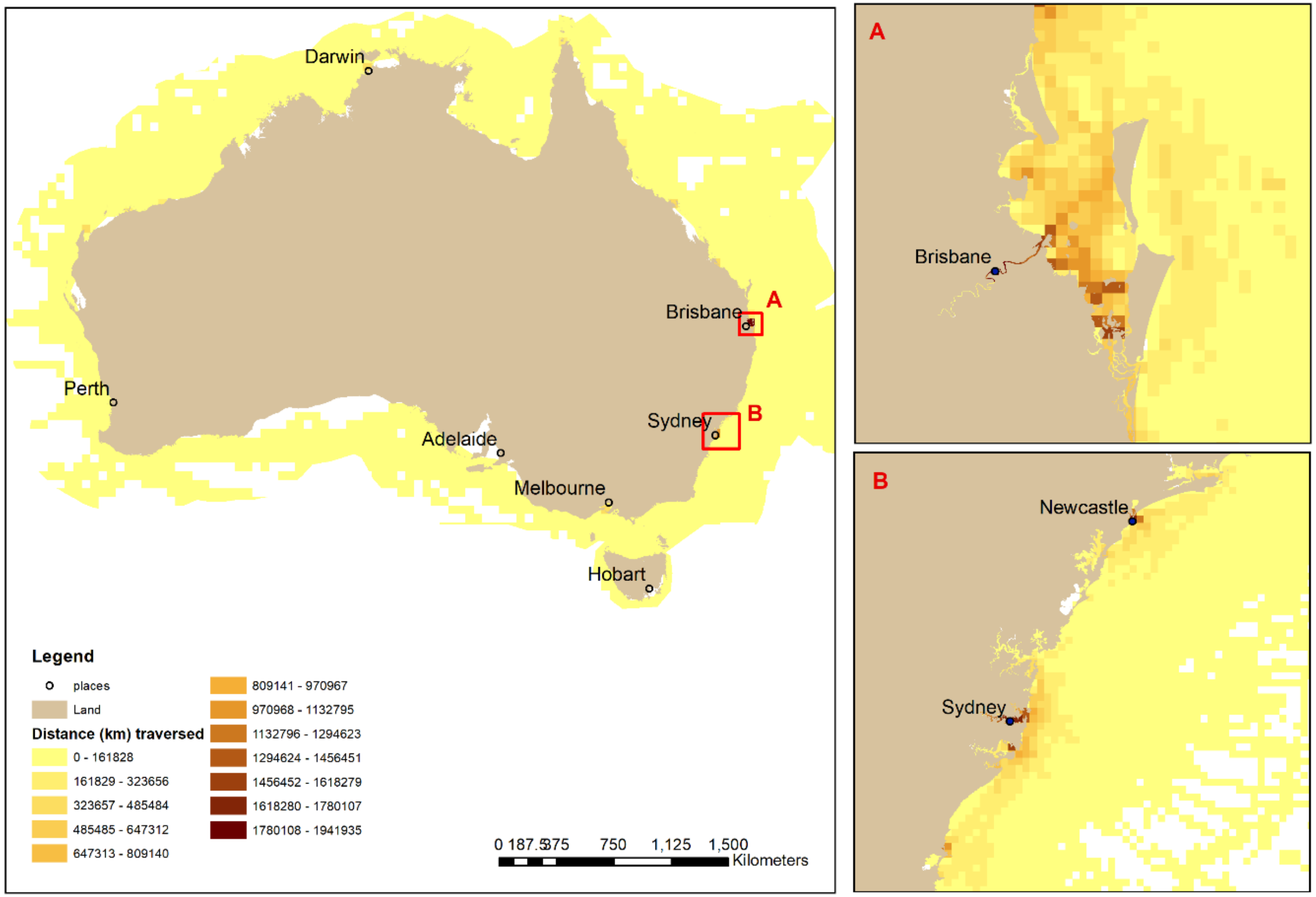


Figure 9 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length between 10m - 25m, and example areas (1/30°) of higher density.

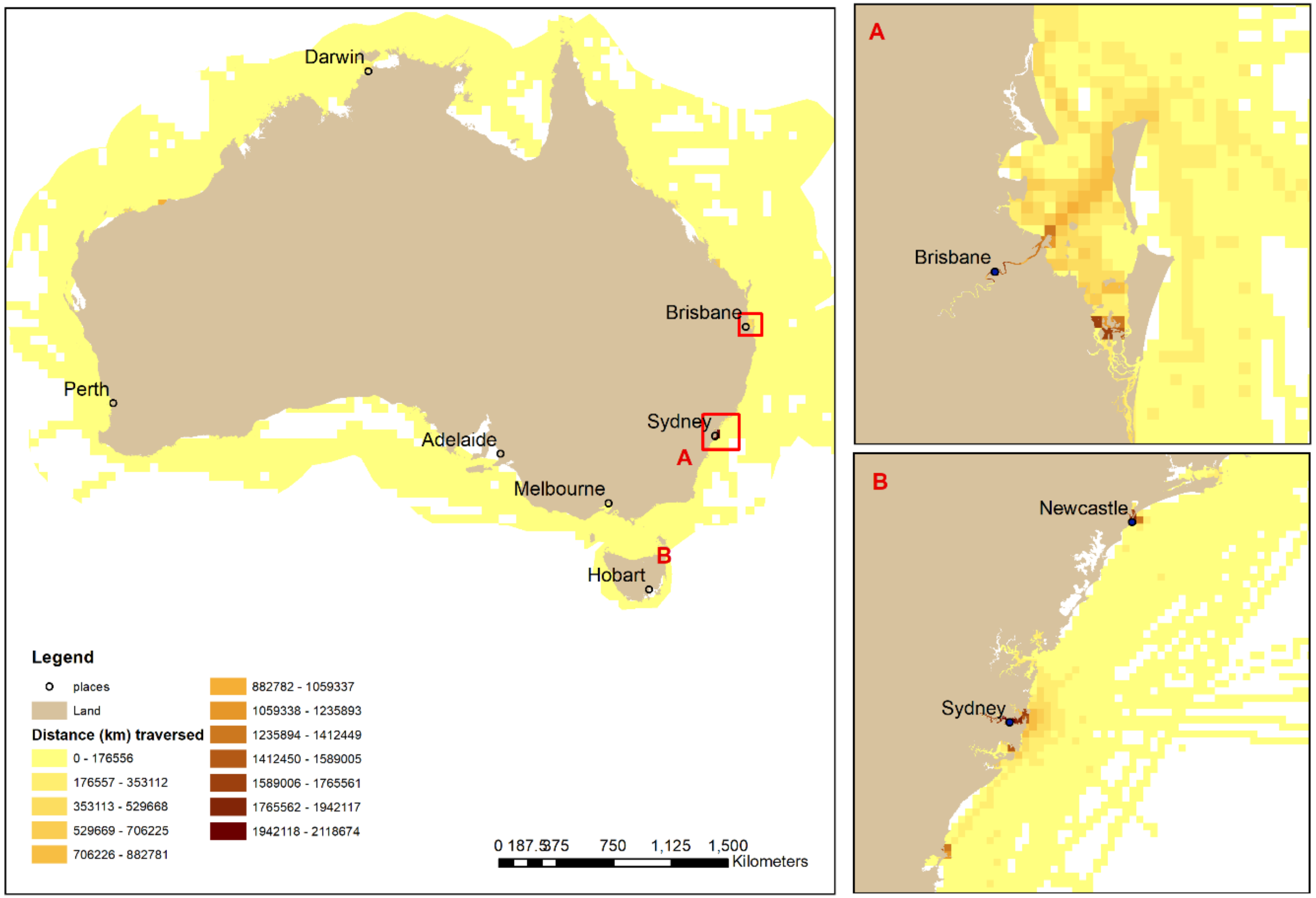


Figure 10 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length between 25m - 50m, and example areas (1/30°) of higher density.

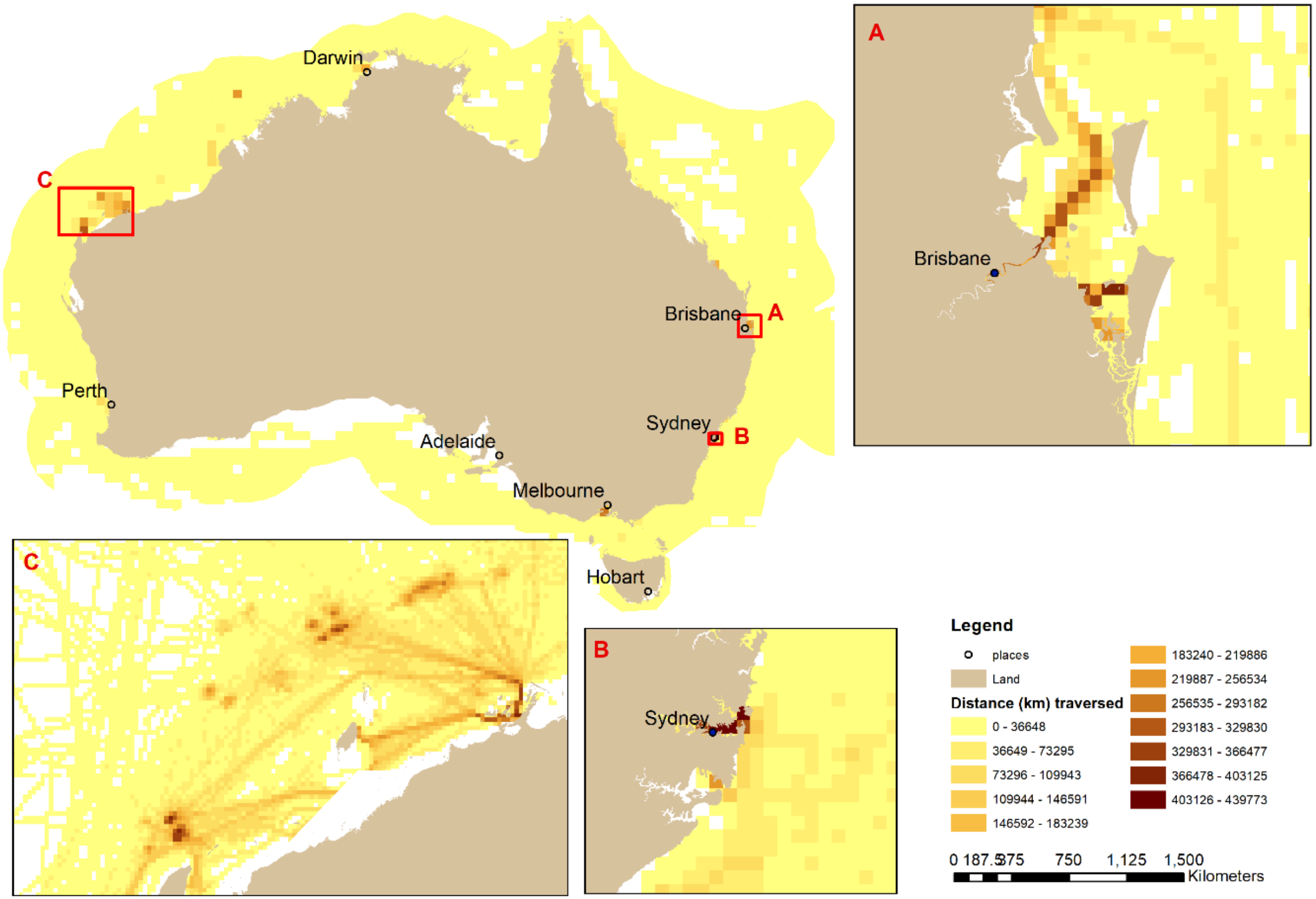


Figure 11 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length between 50m - 100m, and example areas (1/30°) of higher density.

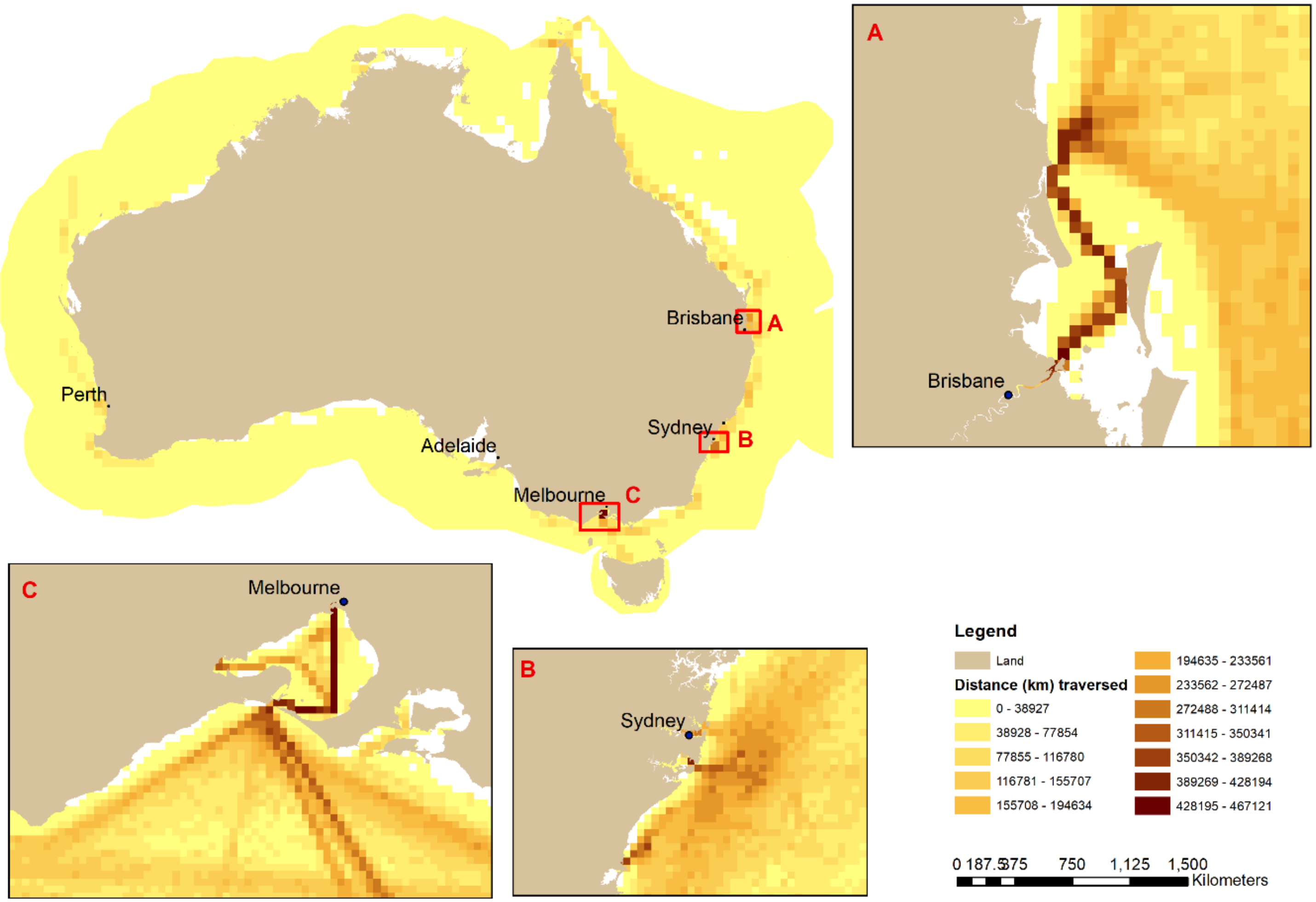


Figure 12 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length between 100m-200m, and example areas (1/30°) of higher density.

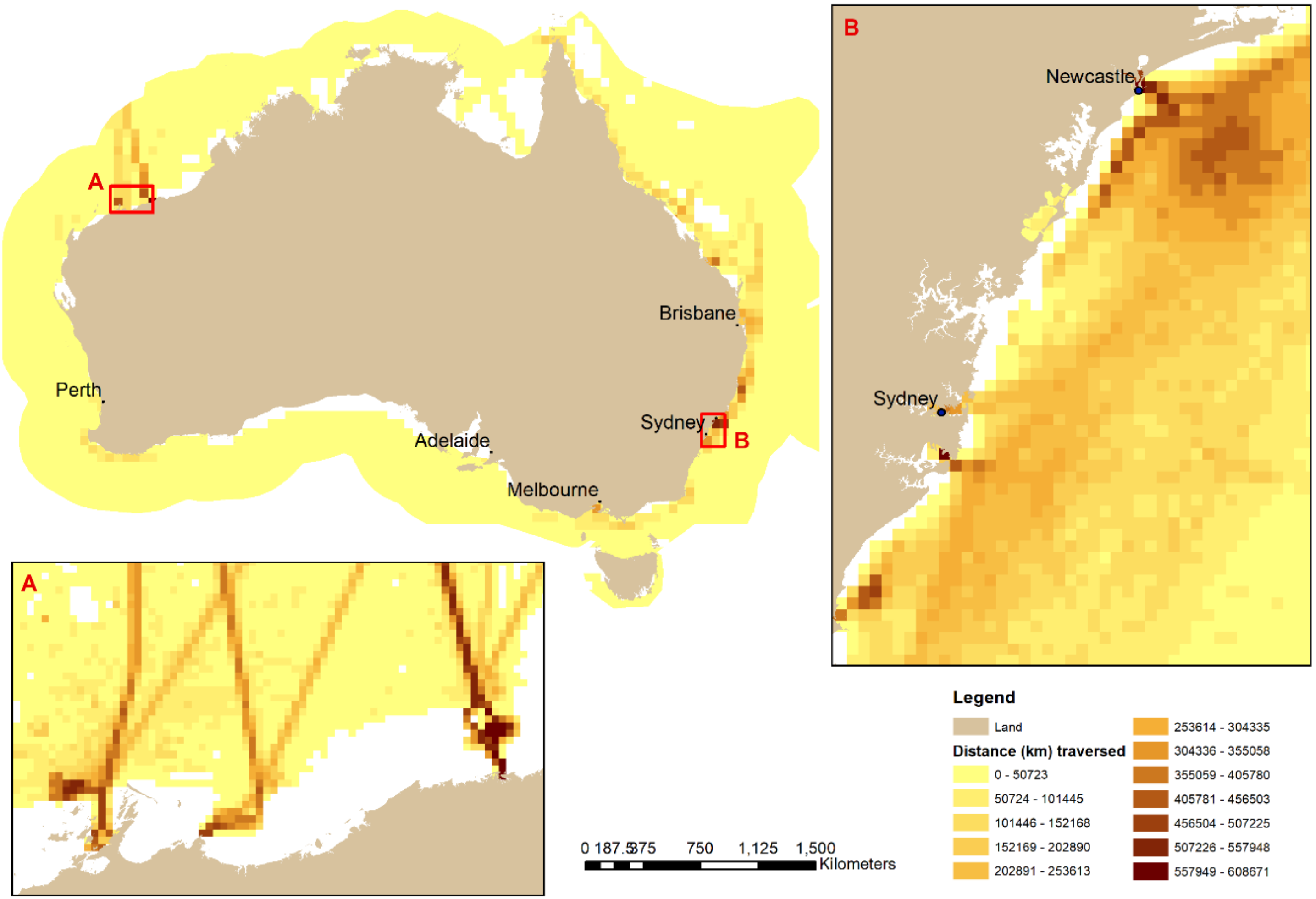


Figure 13 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped vessels with length between >200m, and example areas (1/30°) of higher density.

5.1.2 Maps of vessel density for various vessel types

This section contains maps of vessel density split by vessel type and/or class described in Table 7. Total km travelled by each vessel type is given in Figure 5.

Table 7 Overview of general vessel types

Vessel types	Details
Cargo	Vessels predominantly carrying cargo, e.g., bulk carriers, container ships.
Fishing	Vessels that have identified as fishing vessels, e.g., trawlers, long liners, factory vessels.
Harbour	Vessels related to ports/harbours activities, e.g., tugs, pilot vessels.
Military	Military vessels, e.g. navy.
Official	Vessels operated by government agencies, e.g., police, customs, search and rescue.
Passenger	Passenger vessels, e.g., ferries, cruise ships.
Recreational	Recreational vessels
Sailing vessels	Vessels that are mainly propelled by sail, e.g., racing yachts. It is possible that some sailing vessels may have been listed in other types instead i.e., passenger
Tanker	Tanker vessels, e.g., oil tankers, gas carriers
Working vessels	Work vessels, e.g., offshore supply vessels, crew boats dredgers, and various specialised vessels.

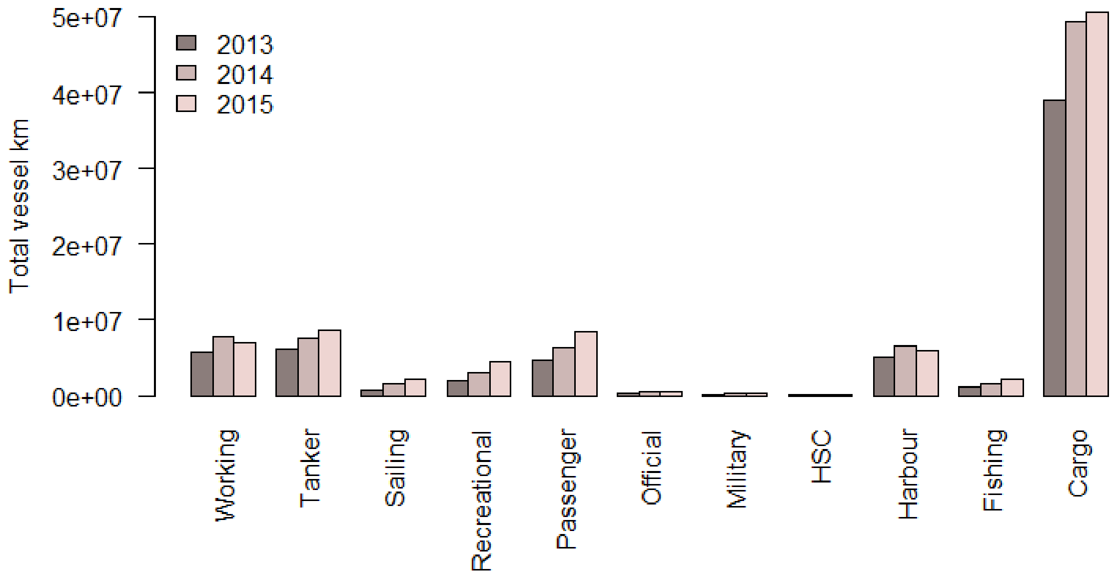


Figure 14 Summary of total vessel km for various vessel types for 2013-2015

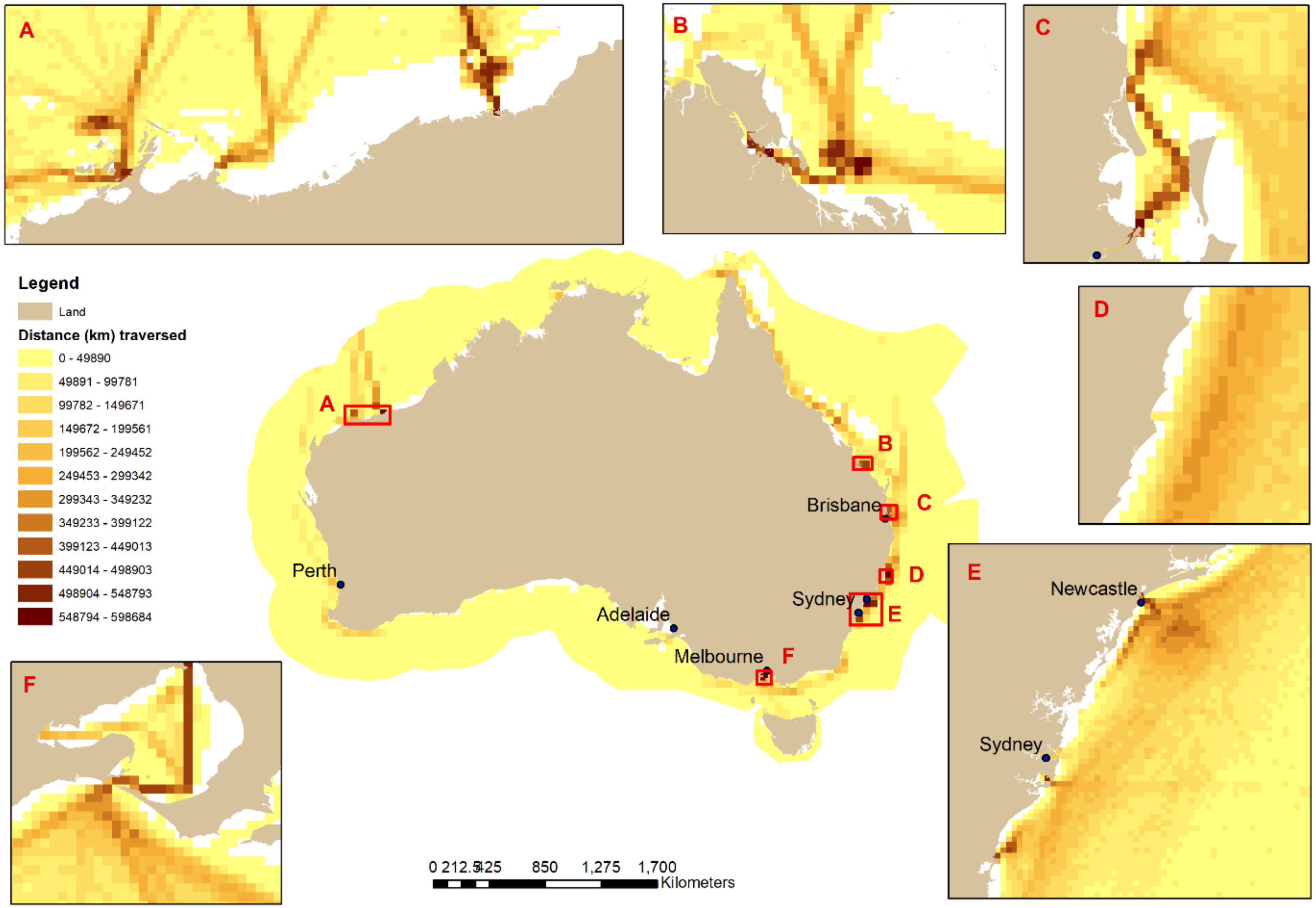


Figure 15 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Cargo vessels, and example areas (1/30°) of higher density.

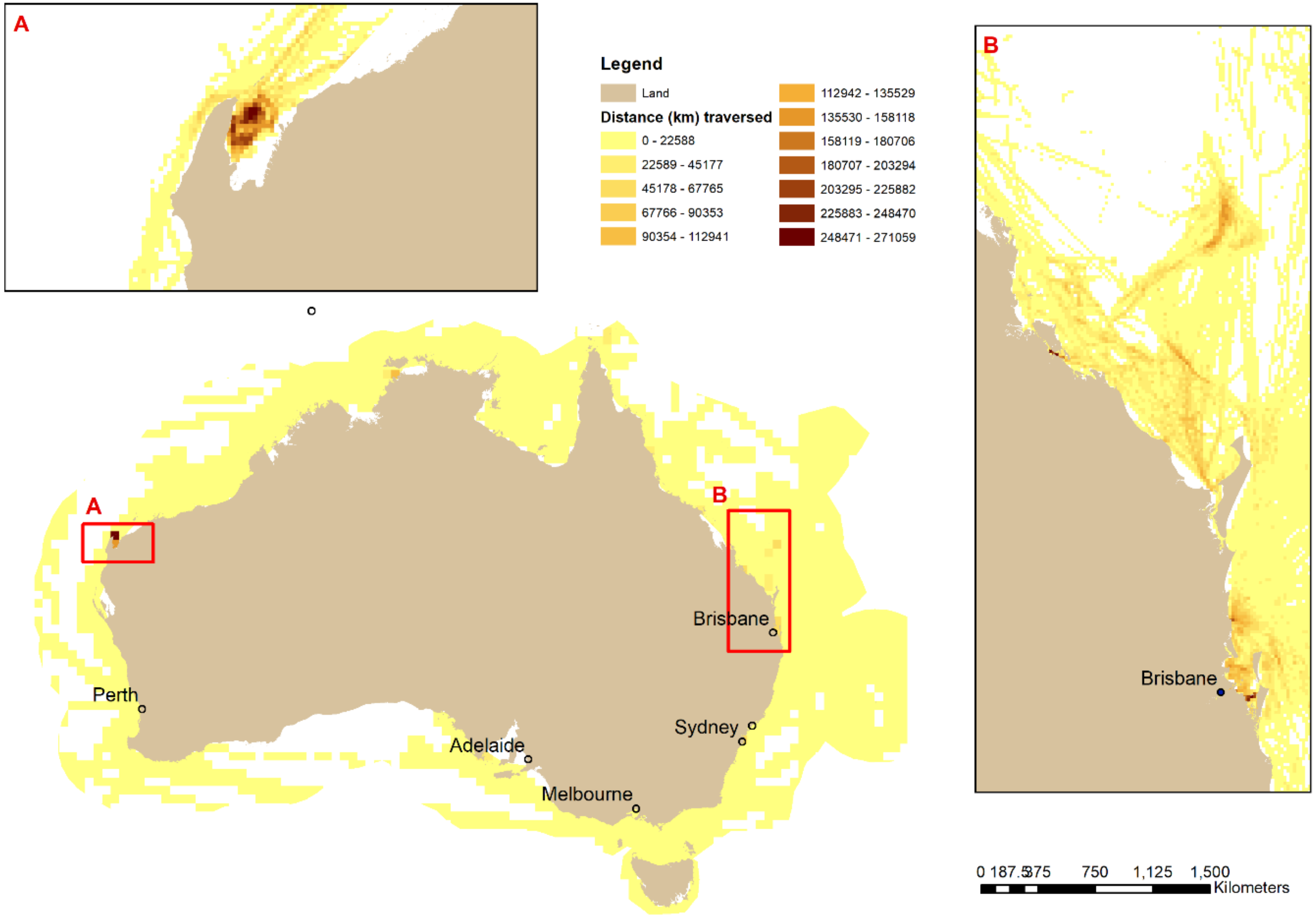


Figure 16 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Fishing vessels, and example areas (1/30°) of higher density.

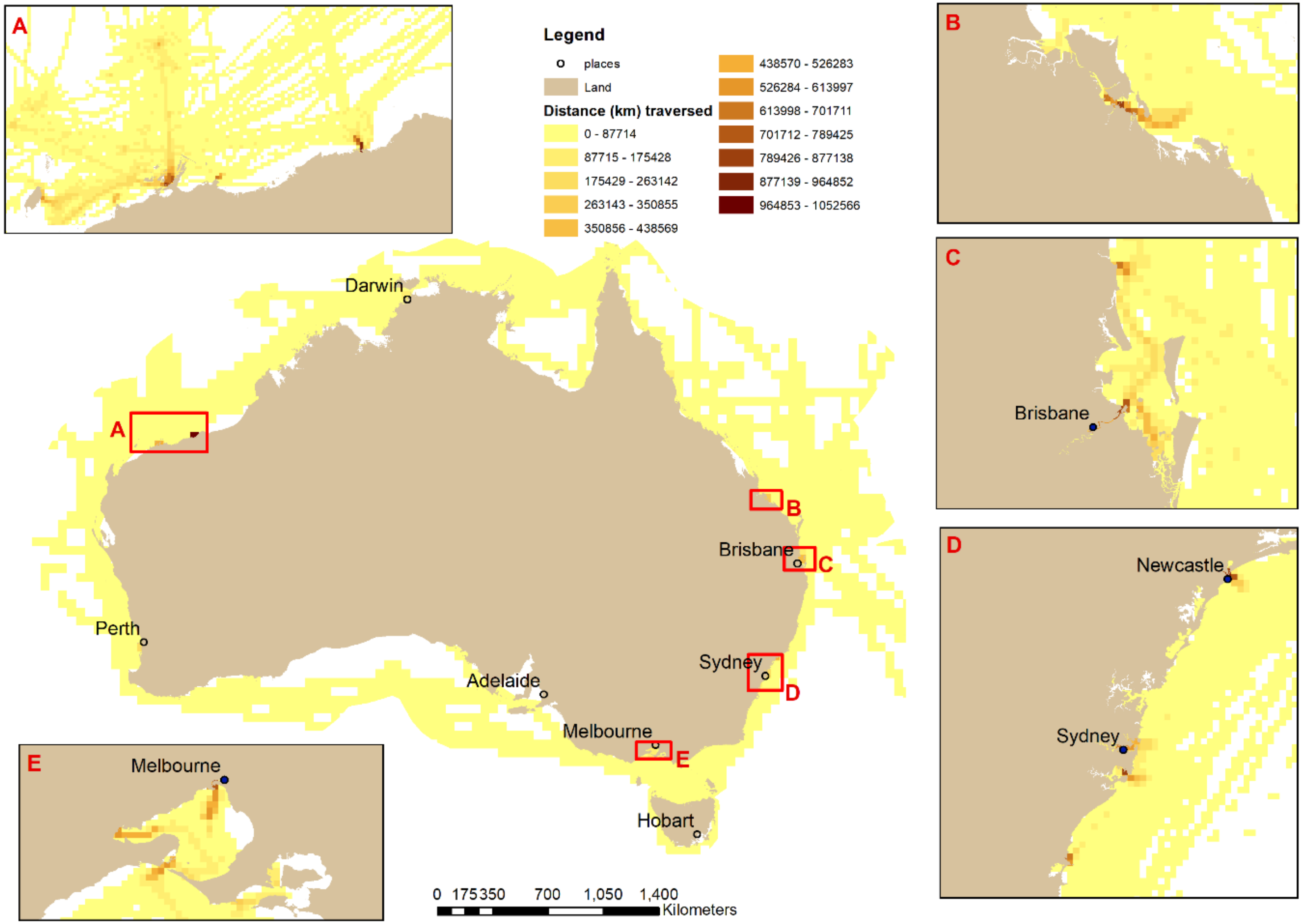


Figure 17 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Harbour vessels, and example areas (1/30°) of higher density.

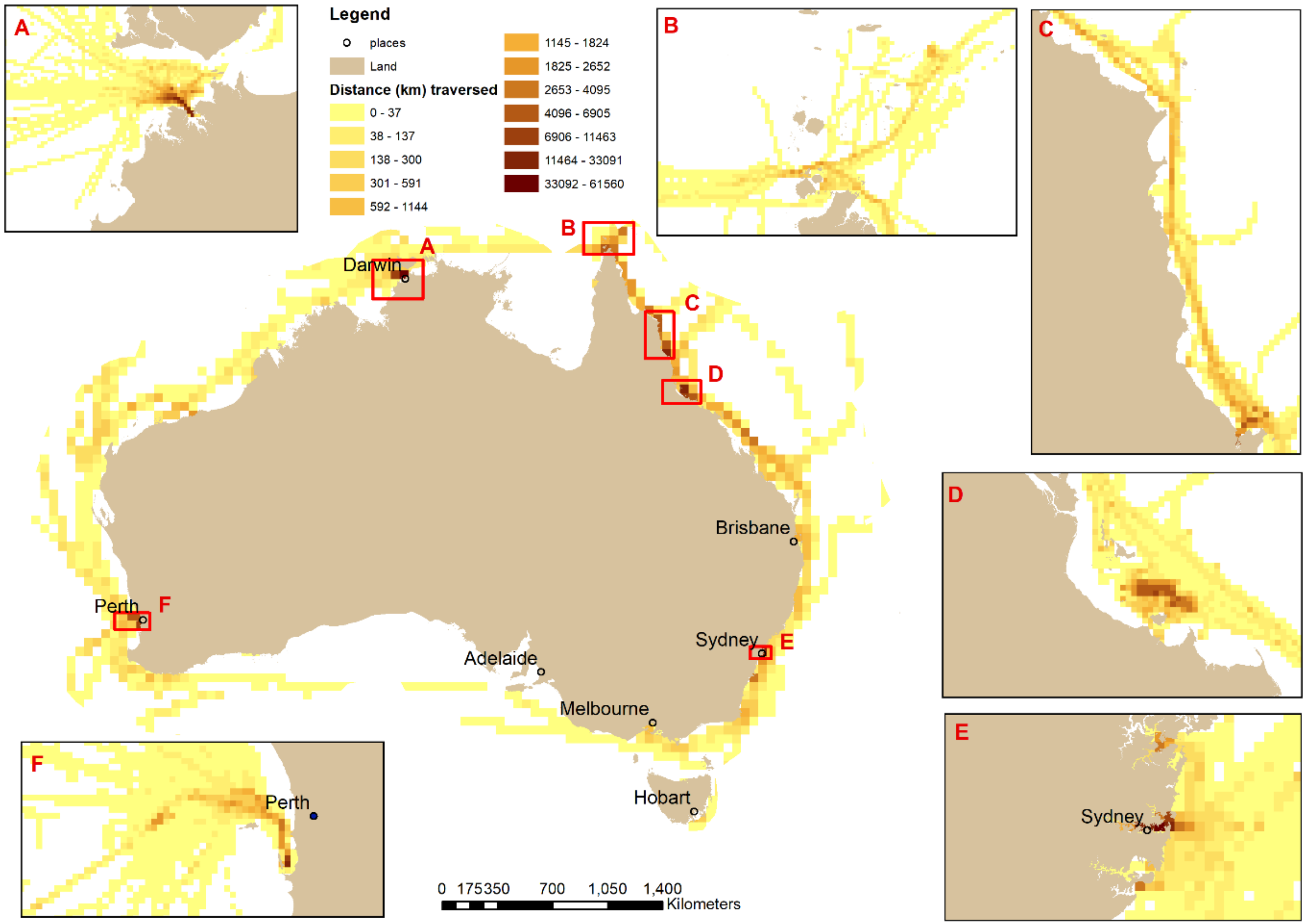


Figure 18 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Military vessels, and example areas (1/30°) of higher density.

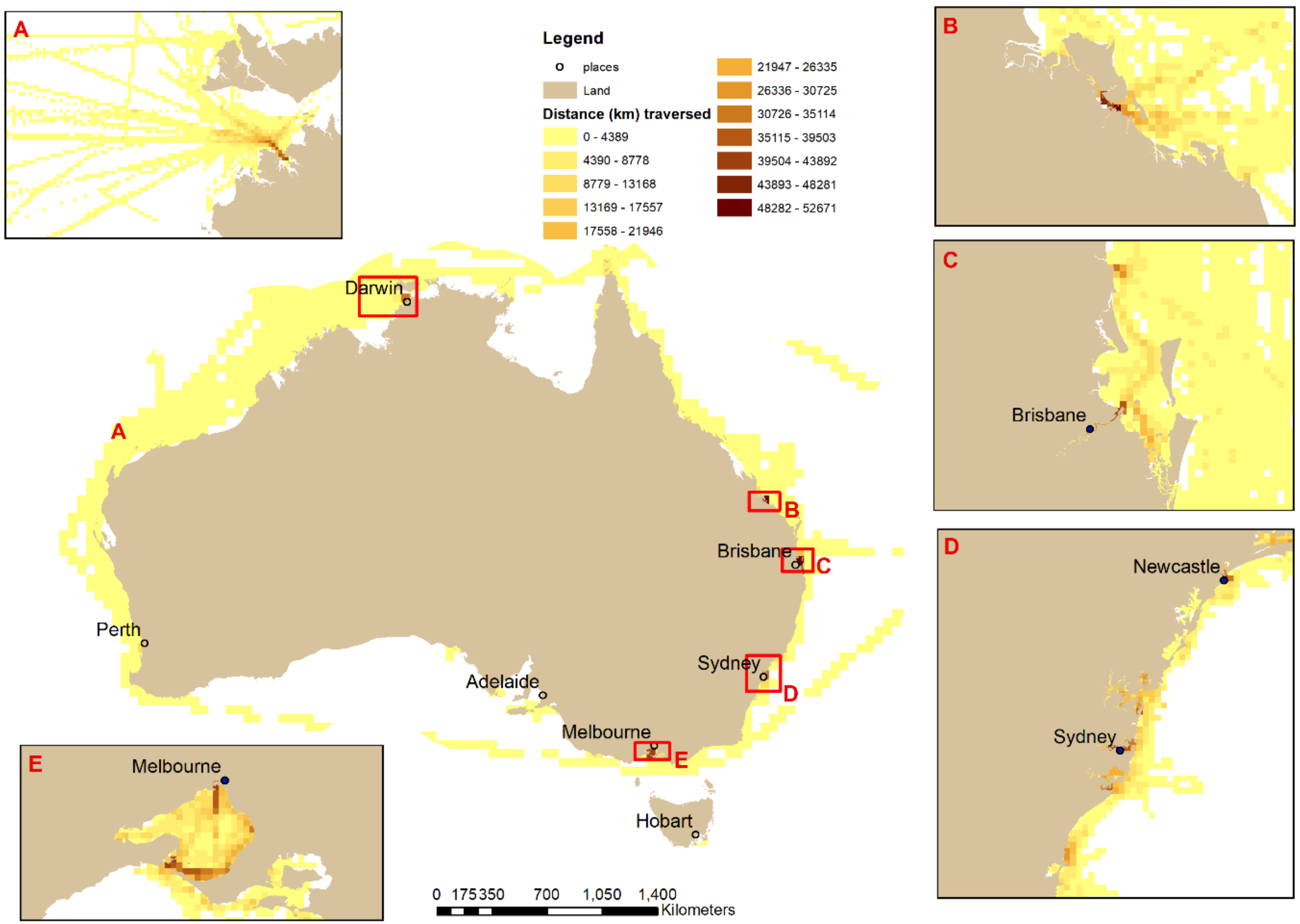


Figure 19 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Official(i.e., Police, ranger, customs, search and rescue etc) vessels, and example areas (1/30°) of higher density.

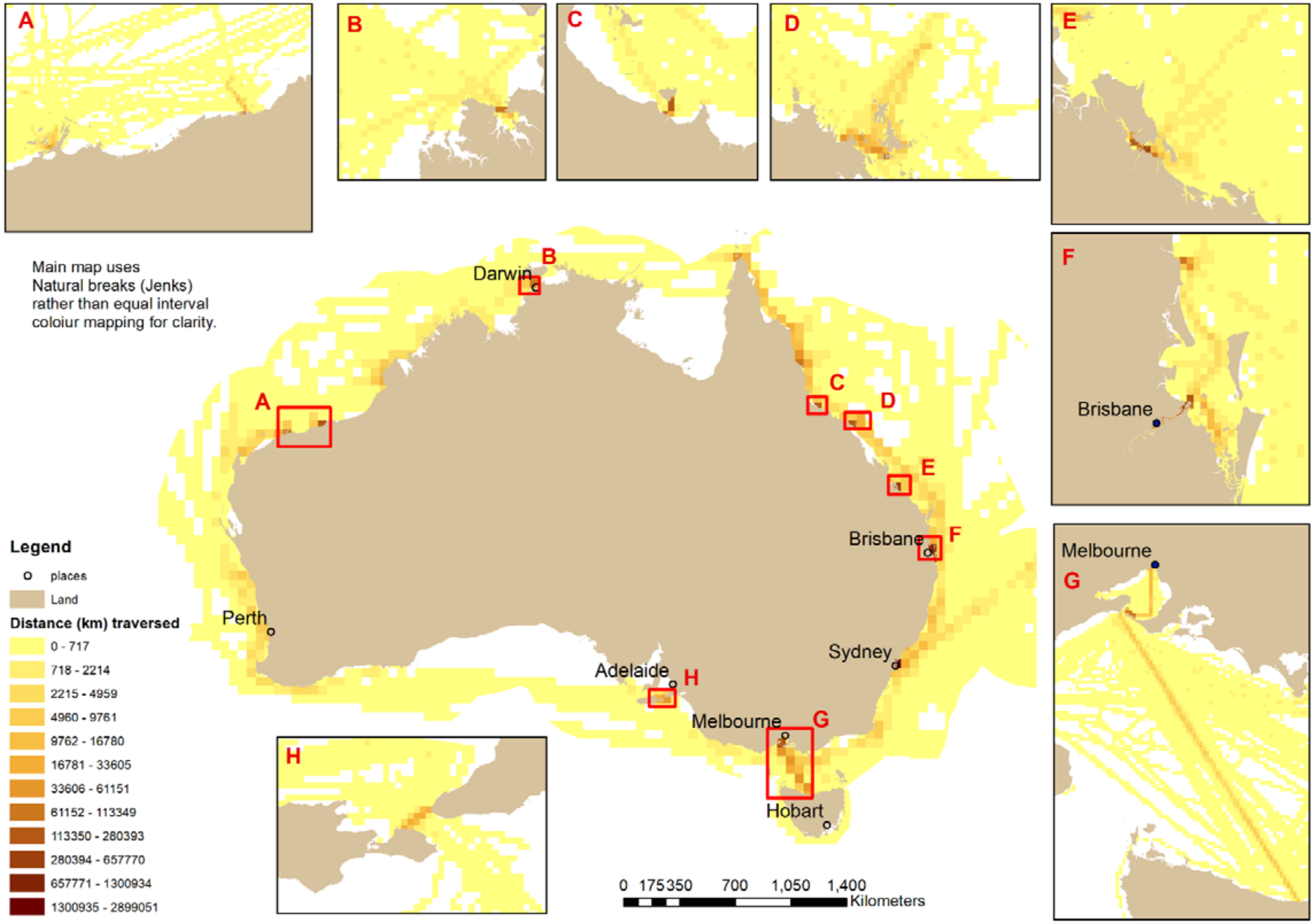


Figure 20 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Passenger vessels, and example areas (1/30°) of higher density.

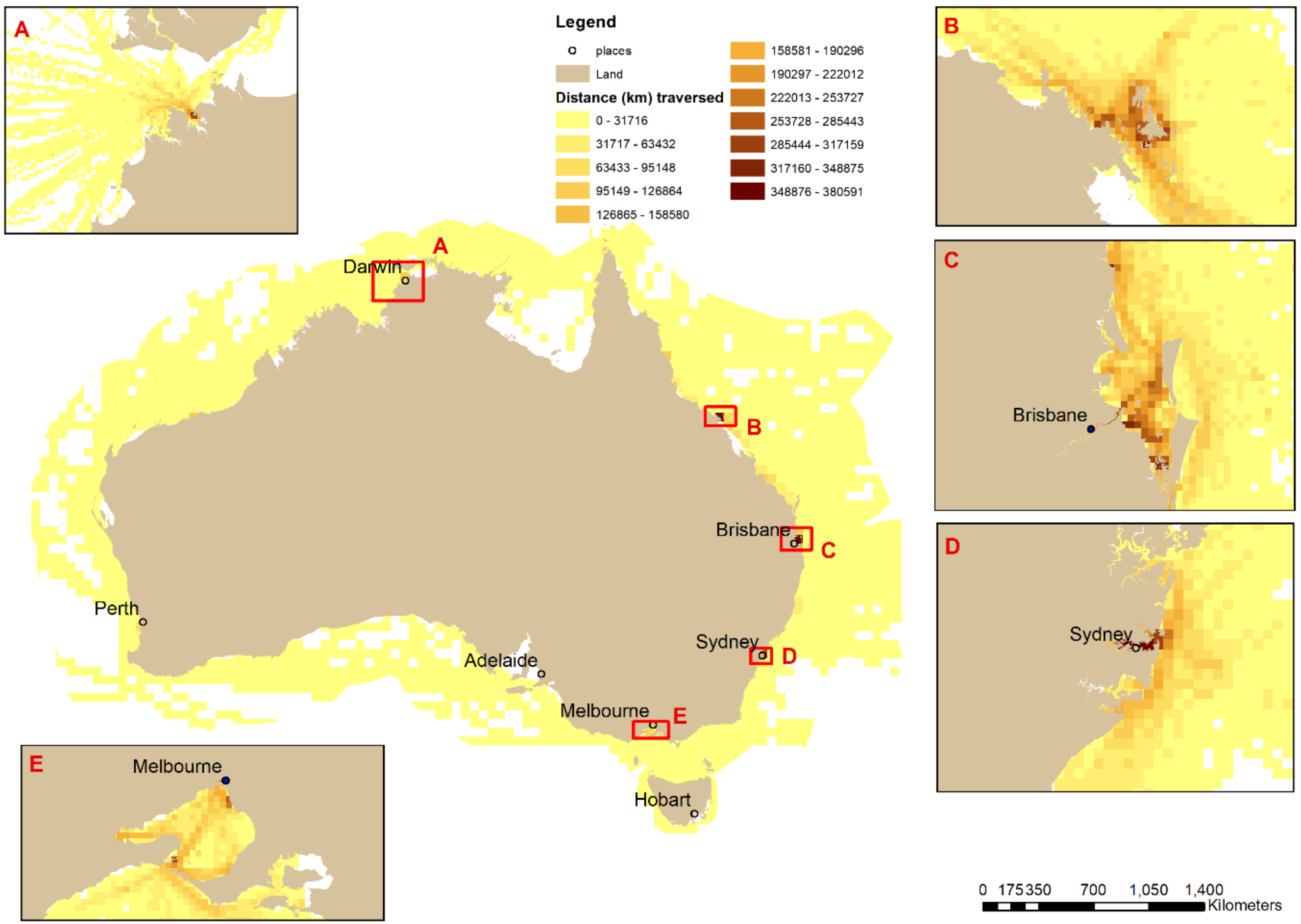


Figure 21 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Recreational vessels, and example areas (1/30°) of higher density.

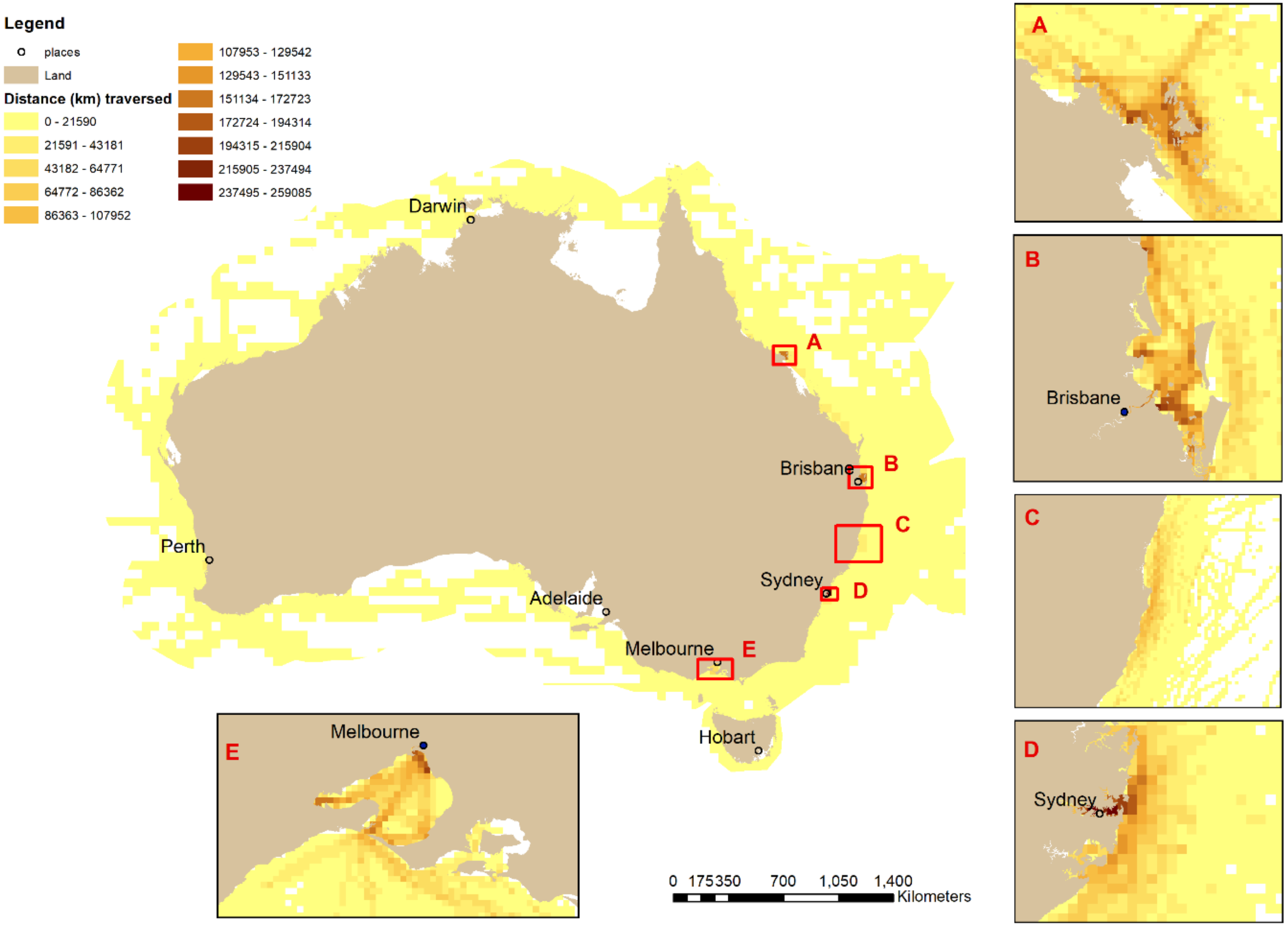


Figure 22 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Sail vessels, and example areas (1/30°) of higher density.

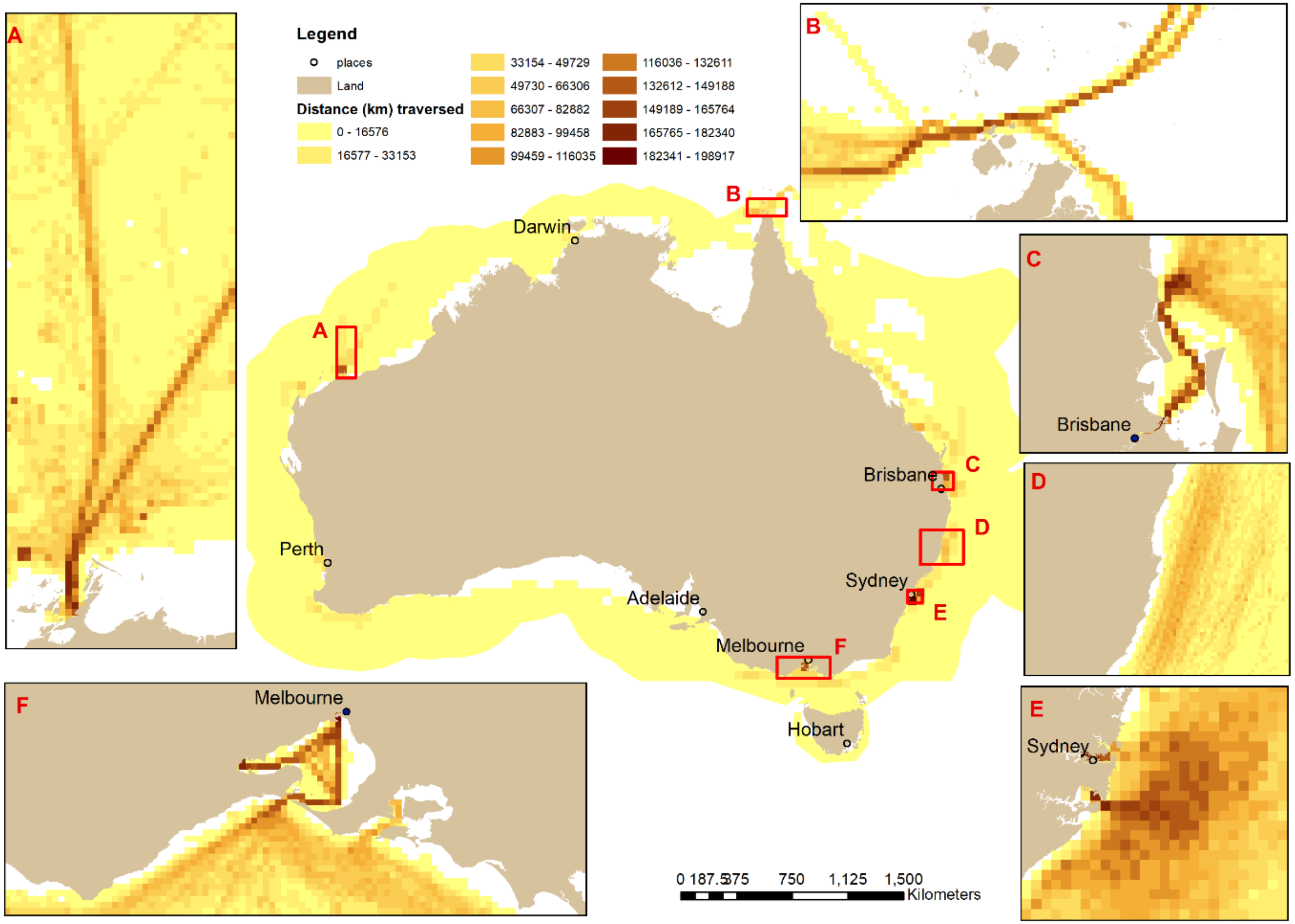


Figure 23 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Tanker vessels, and example areas (1/30°) of higher density.

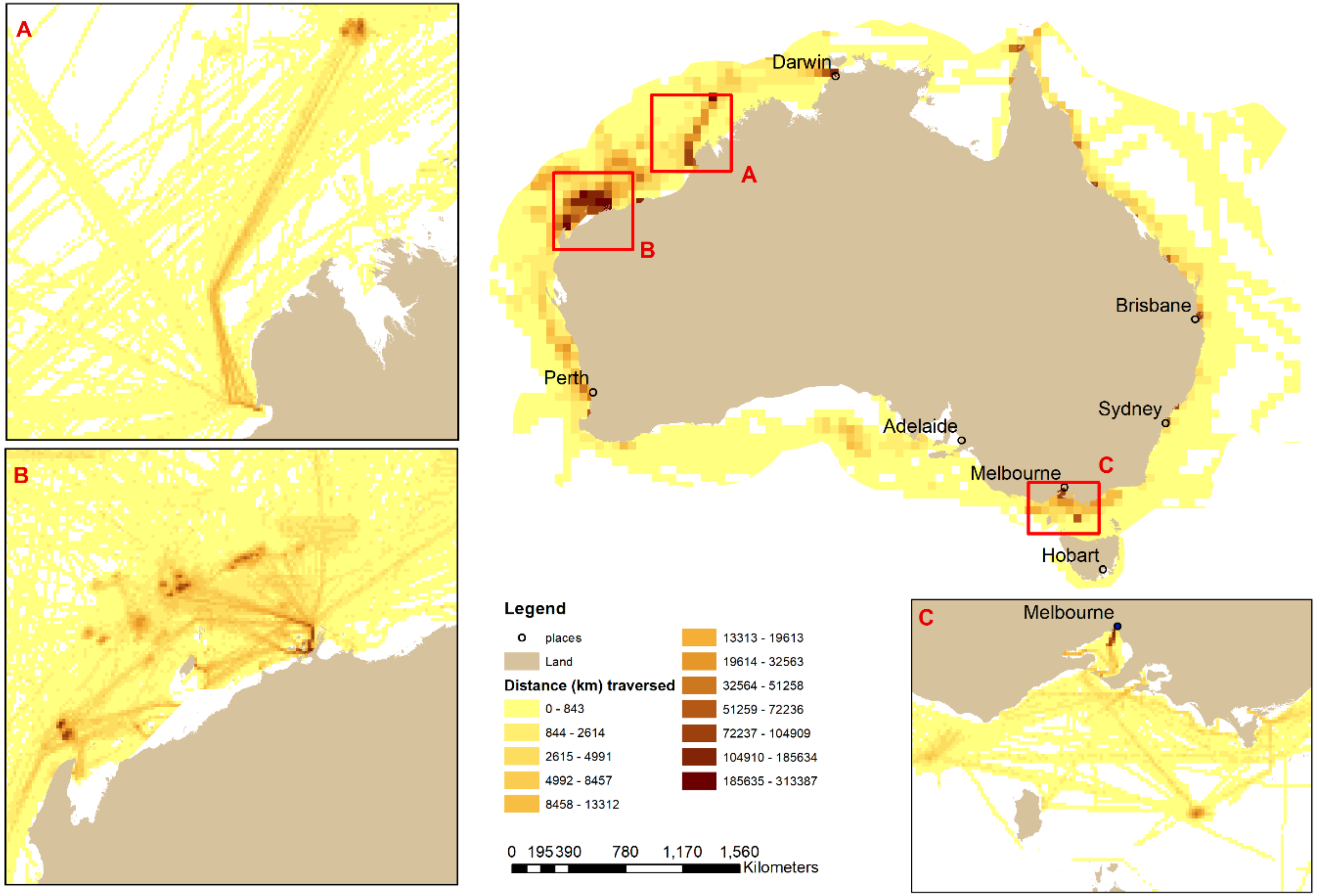


Figure 24 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped Working vessels (i.e., crew boats, offshore supply vessels, specialised vessels such as dredgers), and example areas (1/30°) of higher density.

5.1.3 Maps of vessel density for fast moving vessels

This section contains maps of AIS equipped vessels of any size or type travelling faster than 15knots.

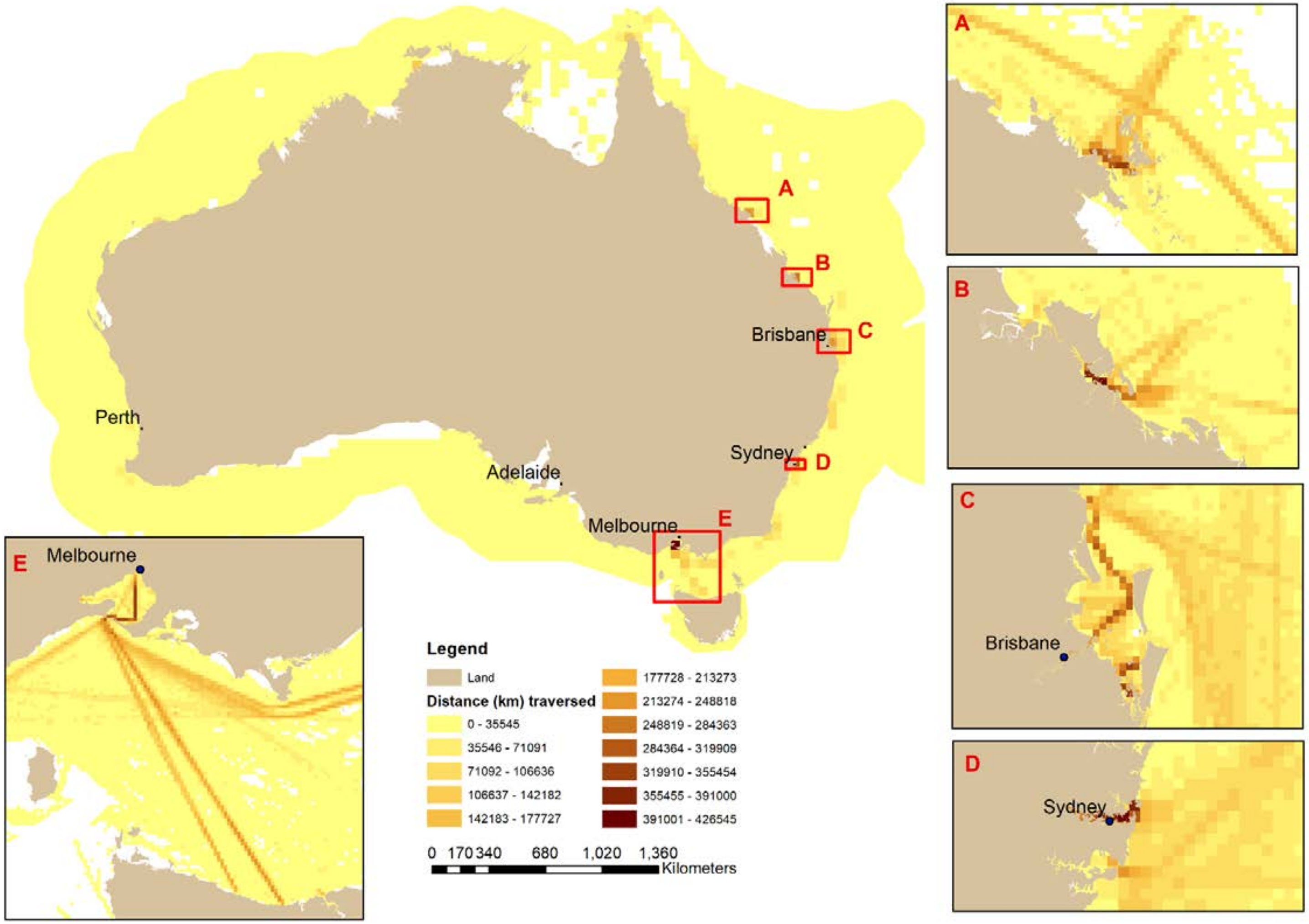


Figure 25 Distance traversed (km) per grid cell (1/2°) in 2015 for all AIS equipped vessels travelling faster than 15kts, and example areas (1/30°) of higher density. Note: Sydney harbour has speed restrictions except for ferries (as demonstrated by the high density in Figure 26)

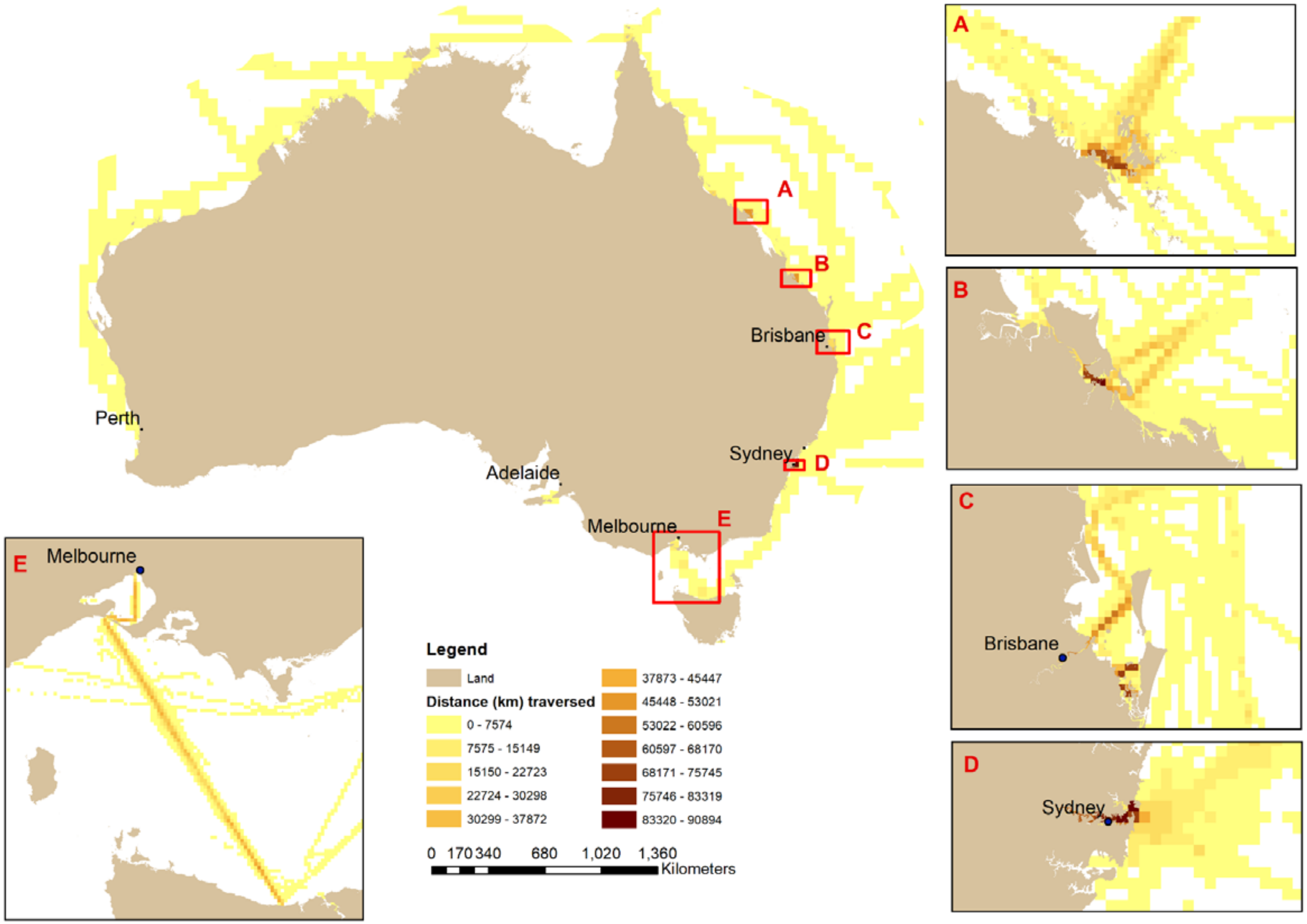


Figure 26 Distance traversed (km) per grid cell (1/2°) in 2015 for AIS equipped passenger vessels travelling > 15kts, and example areas (1/30°) of higher density.

5.1.4 Assumptions and caveats

Assumptions 8 Assumptions and caveats for mapping of AIS equipped vessels

- Not all vessels are required or choose to install AIS equipment therefor not all vessels will be represented in the data. In particular, smaller vessels will be under-represented and hence the true density will be higher than reported here.
- Both vessel size and/or type is often misreported. We made every effort to correct this and get accurate information on every vessel. However, there may be some errors for some specific vessels (especially the smaller class B vessels). Nevertheless, when mapping and analysing across all vessel sizes and types, this will not bias any results. Also, the AIS data set represents the best available data set of its type for Australian vessel movements.
- The polling frequency of vessels is variable and depending on location, vessel density, and AIS equipment, the gap between locations can increase dramatically. In these cases, there can be a great deal of uncertainty on the interpolation between the locations when producing a vessel track. We used various rules to flag when uncertainty is large (See Appendix C), and in some cases when uncertainty was large, the data was left out of the analysis.
- Military vessels may not always have AIS operating and therefore the AIS tracks available may not be fully representative of all military vessel movements.
- Due to drift, currents and positional accuracy, it can be difficult to ascertain from AIS data whether a vessel is stationary or moving. Therefore, in this analysis, it is assumed vessels travelling less than < 4 kts are stationary. Given that the risk of collision and/or injury is most likely minimal at these speeds, this assumption should not bias any vessel strike risk calculations.

5.2 Recreational vessels

In collaboration with NESP project C1, a draft national map of relative density of recreational vessels was developed. This is preliminary work and makes a number of assumptions and approximations.

Data on boat registrations and vessel size was collated for each postcode around Australia[6]. Then, using a data layer of known Australian boat ramps and marinas, the vessels length classes were distributed based on a simple distance weighted function to boat ramps/marinas. This provided an approximate index for each length class at each water access point. Then a simple propagation model was used to propagate from these points out into ocean grid cells based on general information available on distance typically travelled offshore for vessel length classes.

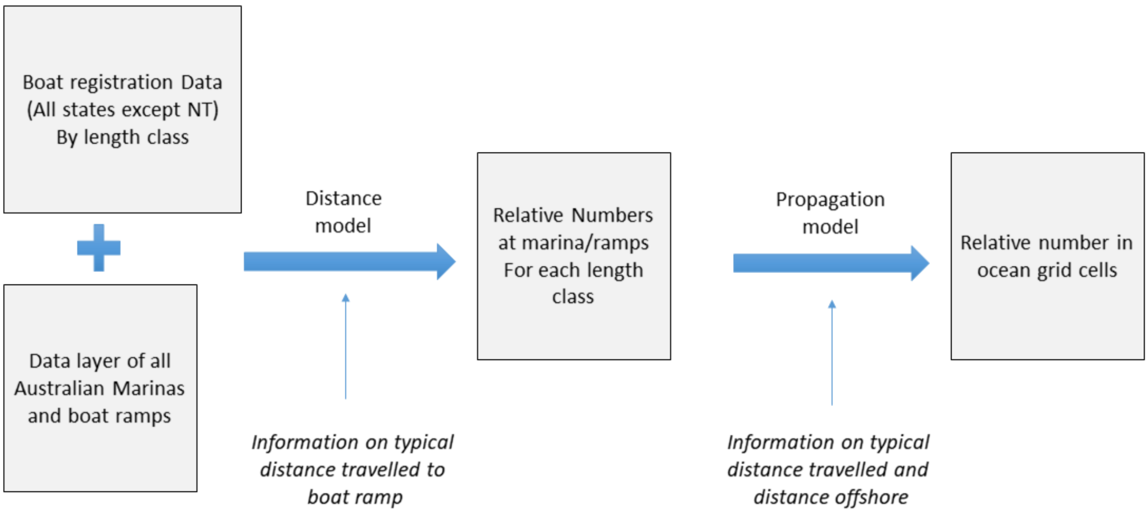


Figure 27 General formulation of recreation vessel calculations

The end result is a relative density. This measure is unit-less and not a direct measure of density but rather aims to be a measure that is proportional to density.

[6] Vessel registration data (de-identified) and boat ramp location data were provided by QLD Department of Transport and Main Roads, NSW Roads and Maritime Services, Transport Safety Victoria, Marine and Safety Tasmania, Department of Planning, Transport and Infrastructure South Australia, and WA Department of Transport. Due to no registrations there is no data for the Northern Territory.

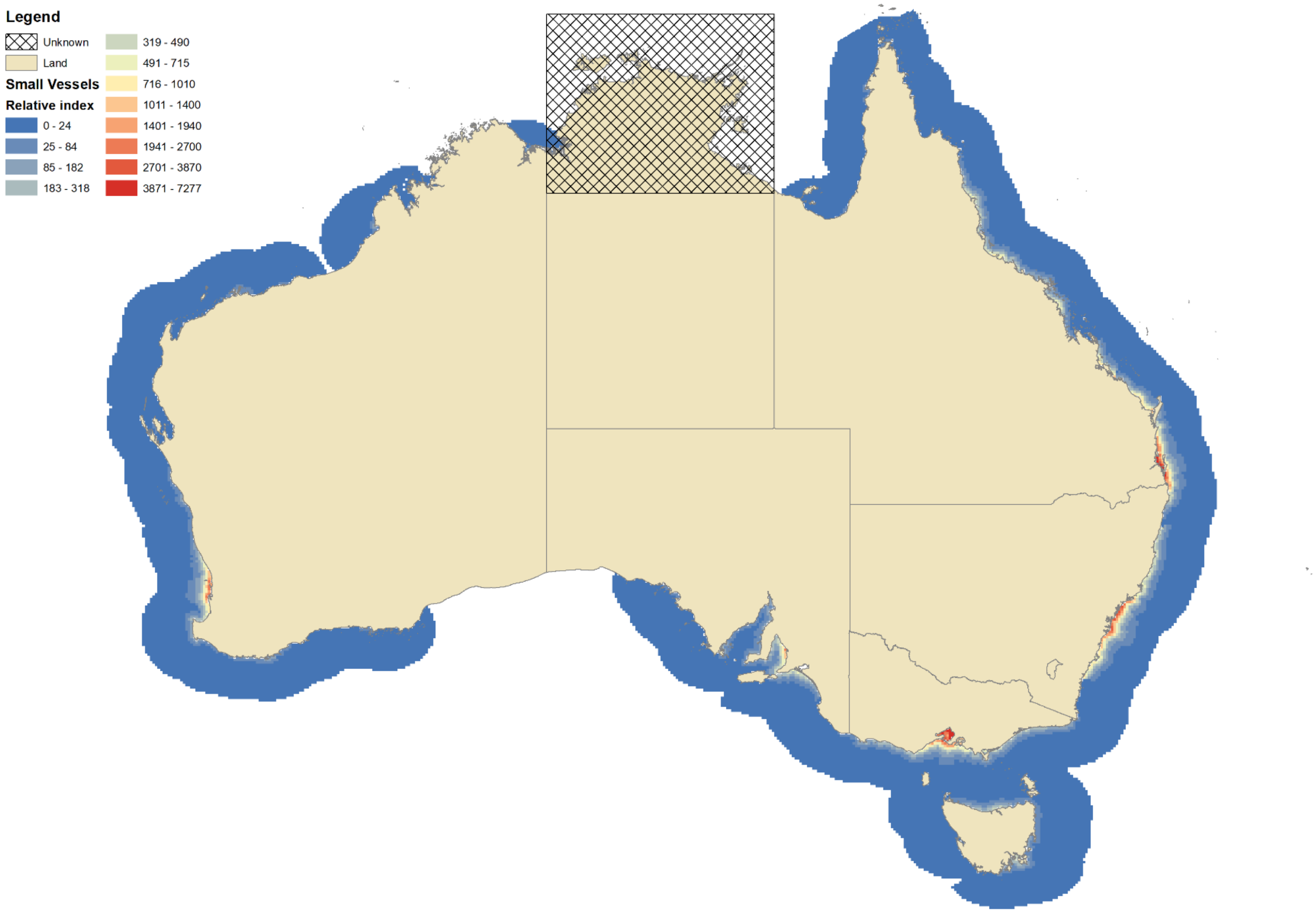


Figure 28 Relative modelled density of non-AIS recreational vessel

5.2.1 Assumptions and caveats

Assumptions 9 Assumptions and caveats for recreational vessel data modelling

- The measure is a relative index only.
- An approximate model for allocation to boat ramps/marinas is used that assumes vessels travel to the boat ramps closest to the registration address, which we know is not always the case. This can result in areas of low population (and presumably low boat registrations) that have high recreational boat use being under-represented as boat owners may prefer to operate from ramps that aren't closest to their address.
- An approximate model for dispersion from boat ramp/marinas is used that assumes propagation offshore is the same no matter the location (e.g., ignoring differences in exposure, depth of water, etc.)
- The model assumes all vessels do the same number of trips per year. In particular, we assume the number of trips per year does not vary spatially and between boat length classes.
- We have no information on boat numbers for the Northern Territory as they do not have a vessel registration system.

In summary, the developed maps are the best approximation available but should only for used for the assessment of broad-scale patterns.

5.3 Projected future vessel density

To estimate future risk, we utilised projected future spatial vessel densities for 2020 and 2025 from Vander Hoorn (2016)[7]. This dataset provides estimated densities for all vessel sizes of AIS equipped vessels.

5.4 Conclusion/Summary

Conclusion D Summary and key ideas of vessel density information

- This project has developed and now has in place an efficient system/ framework to process AIS vessel data at the national scale.
- The system allows us to easily update the maps going forward with yearly AIS data updates.
- For data up to 2016 we can produce maps broken down specifically by size, type, or speed.

Recommendations to improve analysis in future

[7] With thanks to information from Sabine Knapp (pers. Comm.)

- Further work is needed on the recreational vessel modelling. This work is planned in 2018-2019 in NESP project E2.
- Update vessel type/info table for data from 2016 to the present.
- Further investigation of stationary and slow moving vessels to improve accuracy of vessel movements at these low speeds.

6. ANALYSIS FRAMEWORK

6.1 Process Flowchart

The general process is fully automated and is implemented in R/C++/Python. The overall process is shown in Figure 27. Total processing once the AIS database has been queried and stored locally, is in the order of approximately one hour for most maps.

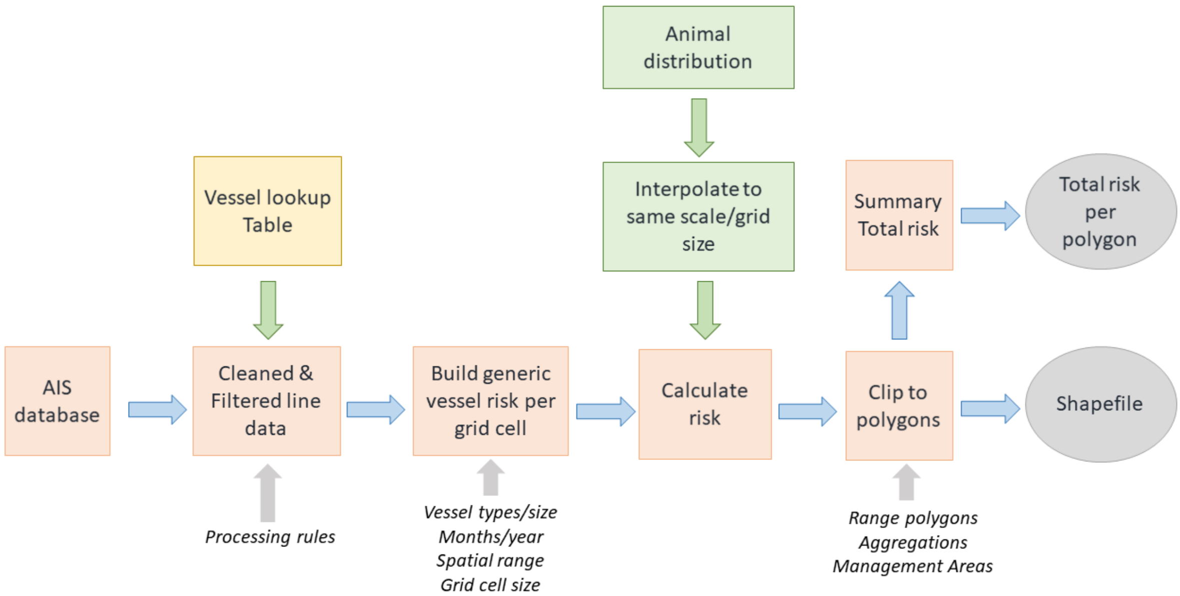


Figure 29 General processing flowchart

6.2 Requirements for any new analysis

To undertake a new analysis on any species, Table 8 provides a summary of the required and optional information.

Table 8 Overview of required information for a new analysis (i.e., shaded cells are required, non-shaded are optional)

Information	Details
Temporal range - Year(s) - Months of the year	Separate maps can be produced for each year of AIS data (currently 2013-2015, with more recent data currently being obtained from AMSA by CSIRO) For migratory species that are not present in Australian waters year-round, we need to know the months when they are present
Vessels of concern - Vessel size (e.g., length) - Speed range (e.g., >15kts) - Type of vessel (e.g., cargo)	If there is information on which vessel characteristics pose a risk to a species (e.g., fast moving vessels only) or alternatively, if for a management question you require the risk calculated for certain types of vessel, the analysis can be limited to that type.
Animal distribution A grid of animal densities OR Polygons describing species range and/or aggregations	The best hypothetical situation would be where we have a reasonable animal distribution model for the whole year and whole population as well as distributions of sub-groups that may be present with different probability of vessel collision (e.g., for whales, mother-calf groups versus adult groups). In the absence of detailed density information, polygons describing species range can be used. Although it then must be assumed that the density is uniform within the species range. If polygons describing aggregation or important areas can be provided, the risk can be compared between aggregation areas. If some relative abundance can be quantified for the aggregations the risk estimate should be reasonable, otherwise the assumption must be made that each aggregation contains the same density of animals.
Map information - Grid cell size - Projection - General Spatial range (e.g., min/max long & lat)	We recommend choosing two grid sizes (e.g., large & small) and producing 2 separate maps at these scales, depending on the overall scale of the map (see Section 3.3.1)
Biological information - Surface availability - Avoidance probability and other behavioural responses	Biological/behavioural information that can affect collision risk will improve the accuracy of the risk analysis. The risk metric currently produced is a relative population wide value which could be improved with more detailed sub-population values that capture greater heterogeneity in the population (e.g., surface availability for calves and adult animals rather than a single value).

6.3 Possible uses/applications

The relative risk analysis can be used to answer a number of questions. Table 9 provides a list of some possible applications.

Table 9 Examples of some possible uses/applications of relative risk framework

Use	Description
Identifying areas of highest relative risk	As per this report relative risk can be used to identify areas that have higher relative risk to help direct further resources, monitoring and/or mitigation options. For example, see Peel et al. (2015).
Compare mitigation options	If mitigation options are being considered, relative risk maps can be produced based on each option and total risk compared. For example, Redfern et al. (2013) looks at changing shipping lane locations.
Assess the effect of existing management changes or future management changes	Changes in vessel behaviour due to management decisions not related to vessel strike can also be assessed for their implications for vessel strike risk. For example, Smith et al. (In prep) examines the change in risk to humpback whales after the International Maritime Organization route changes in the Great Barrier Reef Marine Park.
Assess the effect of port proposals	By predicting increased vessel traffic and likely routes, hypothetical relative risk maps can be made and overall cumulative risk calculated and compared to current total risk to give a percentage change in risk.

6.4 Conclusion/Summary

Conclusion E Summary and key ideas of vessel density information

- This project now has in place an efficient system/framework to process and calculate spatial vessel strike risk.
- Going forward, we can easily update or produce species risk maps as new data/information on species become available,
- Key considerations when using risk maps produced by this framework:
    - The maps show relative risk; and
    - The maps are accurate relative to the available information and the assumptions made.

Recommendations to improve risk analysis

- Currently, no uncertainty (See Appendix E) is propagated to the final risk measures. Quantifying this uncertainty is extremely important to be able to determine if differences in relative risk are statistically significant. Incorporating uncertainty into the risk framework would be relatively straight forward to implement. The main issue currently is the lack of information on the uncertainty of the various parameters that potentially contribute to collision risk (See Appendix E) and in some cases, the animal distribution models.
- In general, the vessel components of the risk calculations are well quantified (the exception being the non-AIS equipped recreational vessels). The analysis can be improved for most species in accurately quantifying the species spatial distribution.
- Further research is needed to refine the risk metrics. Specifically, regarding the issue with the linear assumption of risk and vessel density that is made in all metrics.
- In future, it would be beneficial to incorporate national vessel strike risk into a more general cumulative risk framework as being developed by NESP project E1, and/or the multi-layered vessel risk approach (i.e., Vander Hoorn and Knapp 2015).

7. MARINE FAUNA RISK MAPS

This section contains the risk maps for each of the species selected in Section 2 using current information. These maps can easily be updated as new information becomes available.

The maps presented here are not within themselves the final product or output of the project, but rather examples of the risk map usage. The underlying map data is the final product (AIS and species distribution data), which are available online (see Appendix A) and can be investigated at specific locations to ask various questions. Further state-based maps are available in Appendix D.

Important Note: Within this report generally all the vessel strike risk maps are standardised and what is being shown is a proportion of the total risk for the map in each grid cell. This has been done for comparisons within each map, not for comparison across maps. Specifically, relative risk values presented on one map cannot be directly compared to another map. If this is required the maps for that purpose can be produced.

7.1 Western Australian humpback whale

7.1.1 Data sources

To develop a humpback whale distribution model for the entire West coast of Australia, all identified and available humpback whale sighting datasets were identified and assessed for their suitability of inclusion in a predictive spatial habitat model (How et al., 2015). The majority of the datasets available for this project consisted of relatively clustered sighting data from aerial surveys, due to the nature of the specific coverage for which it was collected. It was identified that the datasets that provided the greatest coverage of humpback whales in the W.A. coastal waters were satellite tag datasets collected by the Fisheries Research and Development Corporation (FRDC) 2014 - 2016 and the Australian Marine Mammal Centre (AMMC) in 2009 and 2011. The satellite tag data were divided into the northward and southward migration movements of whales to derive two final spatial models based on differences in the movement patterns and migration distance offshore between the two migration periods.

Tagging of migrating humpback whales off the W.A. coast occurred at the northern and southern extent of the West Coast Rock Lobster Fishery (WCRLF). Northern migrating whales were tagged at the southern border of the fishery off Augusta, while southern migrating whales were tagged at, or near the northern border of the fishery in Exmouth and Carnarvon. The objective of the FRDC project was to minimise entanglements of humpback whales in the Rock Lobster Fishery and as such the satellite tag data predominantly focussed on the southern and central section of the W.A. coast and provided minimal information on the distribution of whales in the Kimberley region. Consequently, the use of AMMC satellite tracking data in the Kimberley region of southward migrating whales in 2009 and northward migrating humpback whales into the Kimberley region in 2011 were used to inform the distribution model for northern Australia.

A new method was developed to estimate whale distributions from tag movement data (Section 4.2), which we applied to the northern and southern humpback whale migrations separately (Figure 30 and Figure 31). The model produces a density in terms of total cumulative whale time spent in each grid cell of whales migrating in a specified direction. In this report we standardised to give proportion of total whale days of the whole migration, e.g. 1% would indicate 1% of the total time of all whales migrating in the specified direction are in the grid cell in question.

The results of this model were used in conjunction with the AIS data density and recreational boat model to produce various risk maps (see Table 10).

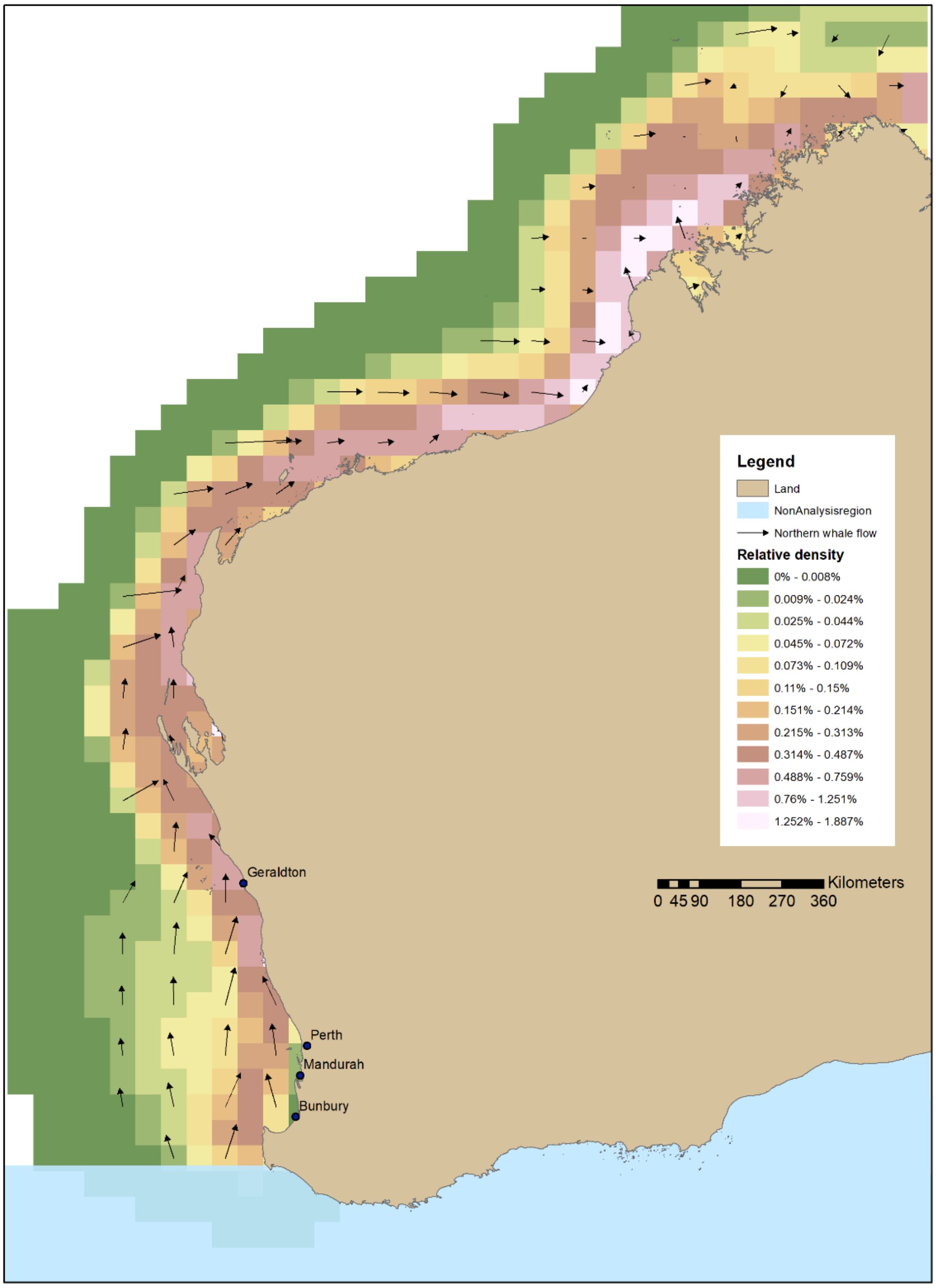


Figure 30 Humpback Northern migration model, with the relative density in terms of proportion of whale days.

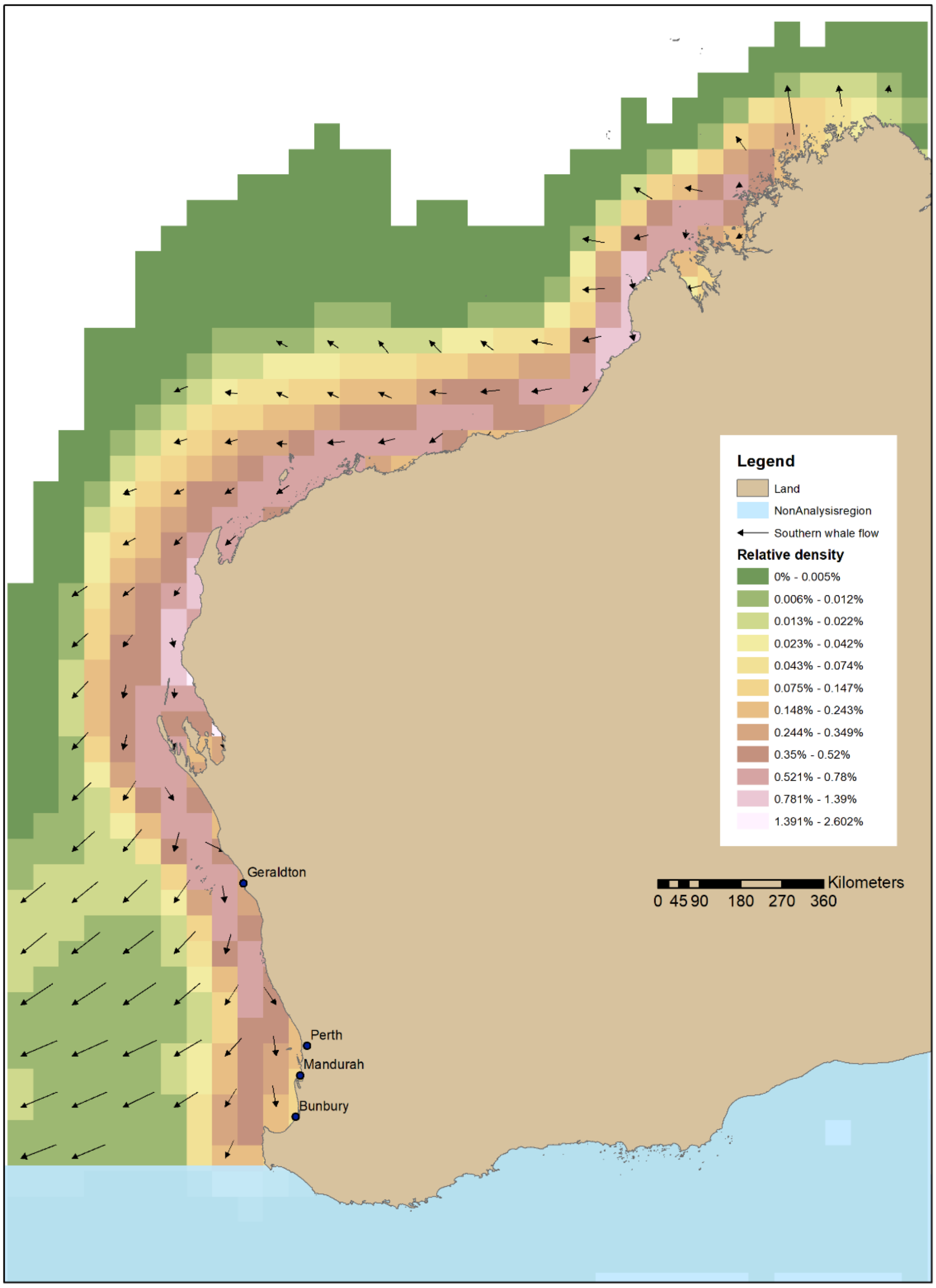


Figure 31 Humpback Southern migration model, with the relative density in terms of proportion of whale days.

7.1.2 Risk maps

Table 10 Summary of data sources and mapping for Australian West coast Humpback whales

Whale Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps/Plots	Figures
Tag tracking data model (See Section 4.2) Source: see Section 7.1.1	Vessels ≥80m Length	2013-2015 AIS Data (See Section 5.1)	Per season (Aug-Sep) 2013-2015 (only 2015 shown in this report)	1/30° 1/2°	Relative risk of a fatal collision (See Section 3.2.1)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 32
	Vessels <80m Length				Relative risk of a collision[8] (See Section 3.2.2)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 33
	Vessels >15kts speed				Relative risk of a collision[8] (See Section 3.2.2)[8] (See Section)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 34
	Recreational Vessels	(See Section 5.2)	Single hypothetical season	1/0°	Relative co-occurrence (See Section 3.2.3)	Core area (at 1/2°) and Higher risk areas (at 1/10°)[9]	Figure 35

[8] For vessels less than 80m we are less sure if the probability of fatality curves are relevant so we only calculated risk of collision.
[9] As the recreational vessel model has much greater uncertainty we examine at larger grid size than the AIS data.

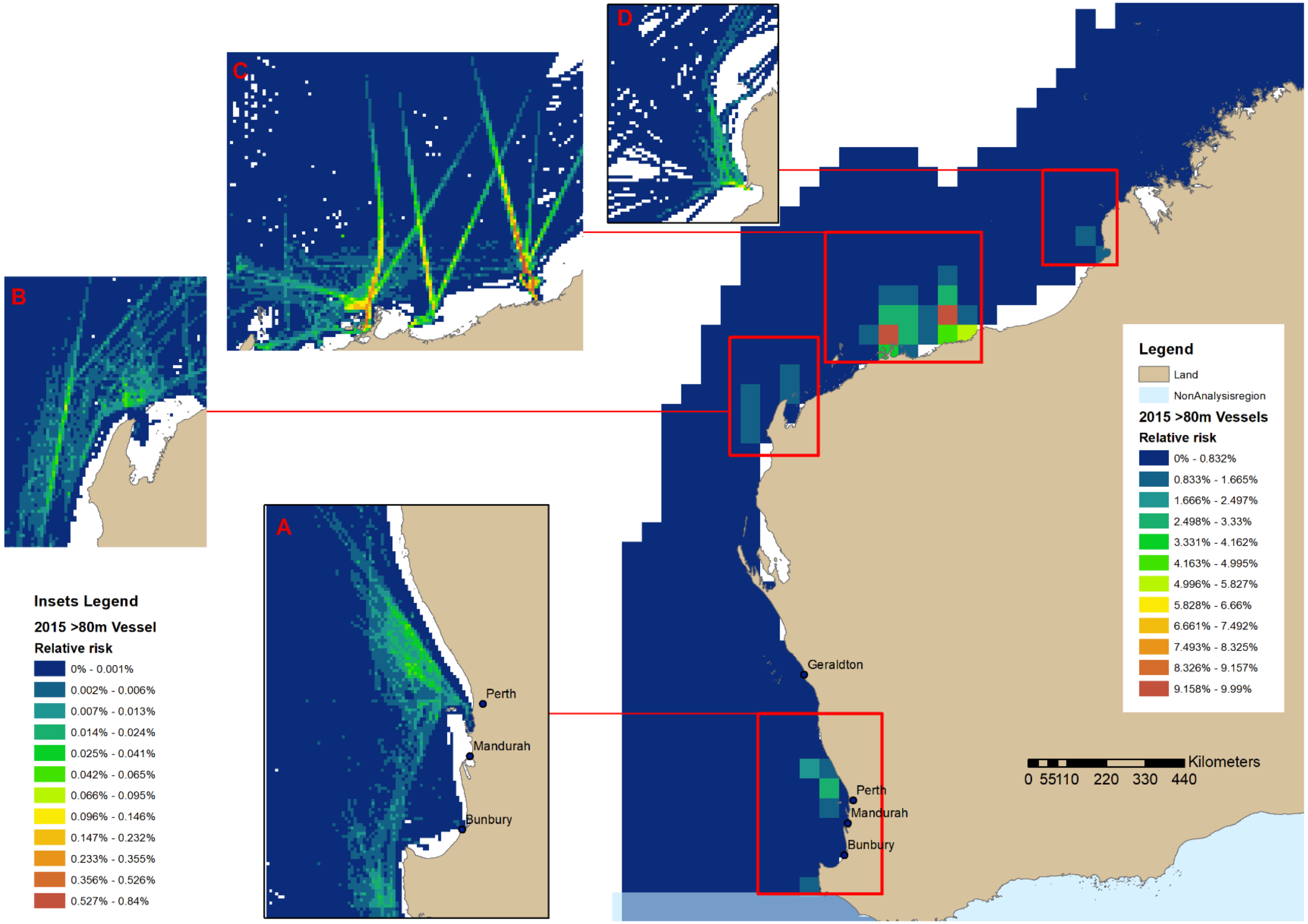


Figure 32 Relative risk of a fatal collision between West coast Humpback whales and large (>80m in length) AIS equipped vessels in 2015, for the combined Northern and Southern migration

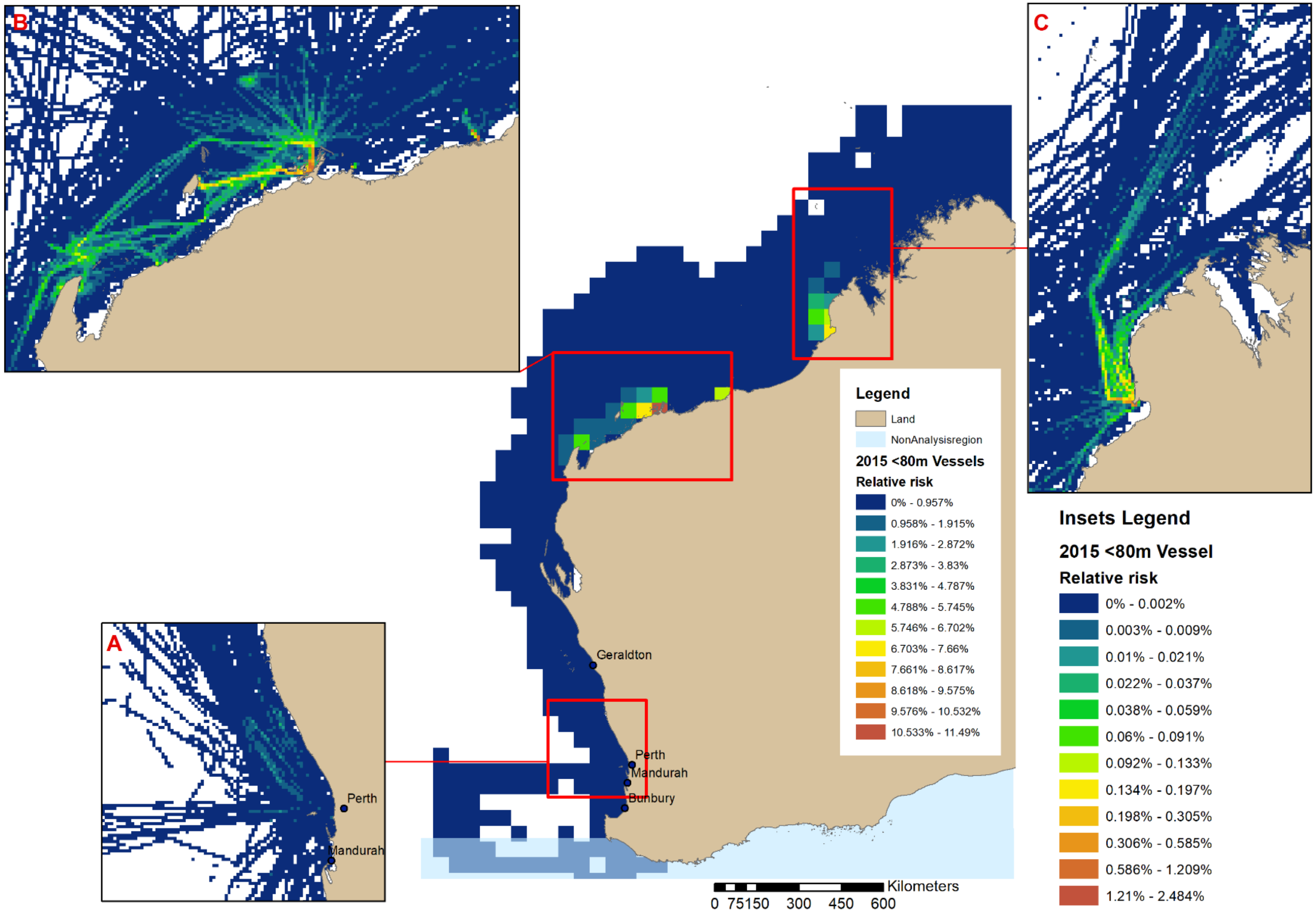


Figure 33 Relative risk of a collision between West coast Humpback whales and small (<80m in length) AIS equipped vessels in 2015, for the combined Northern and Southern migration

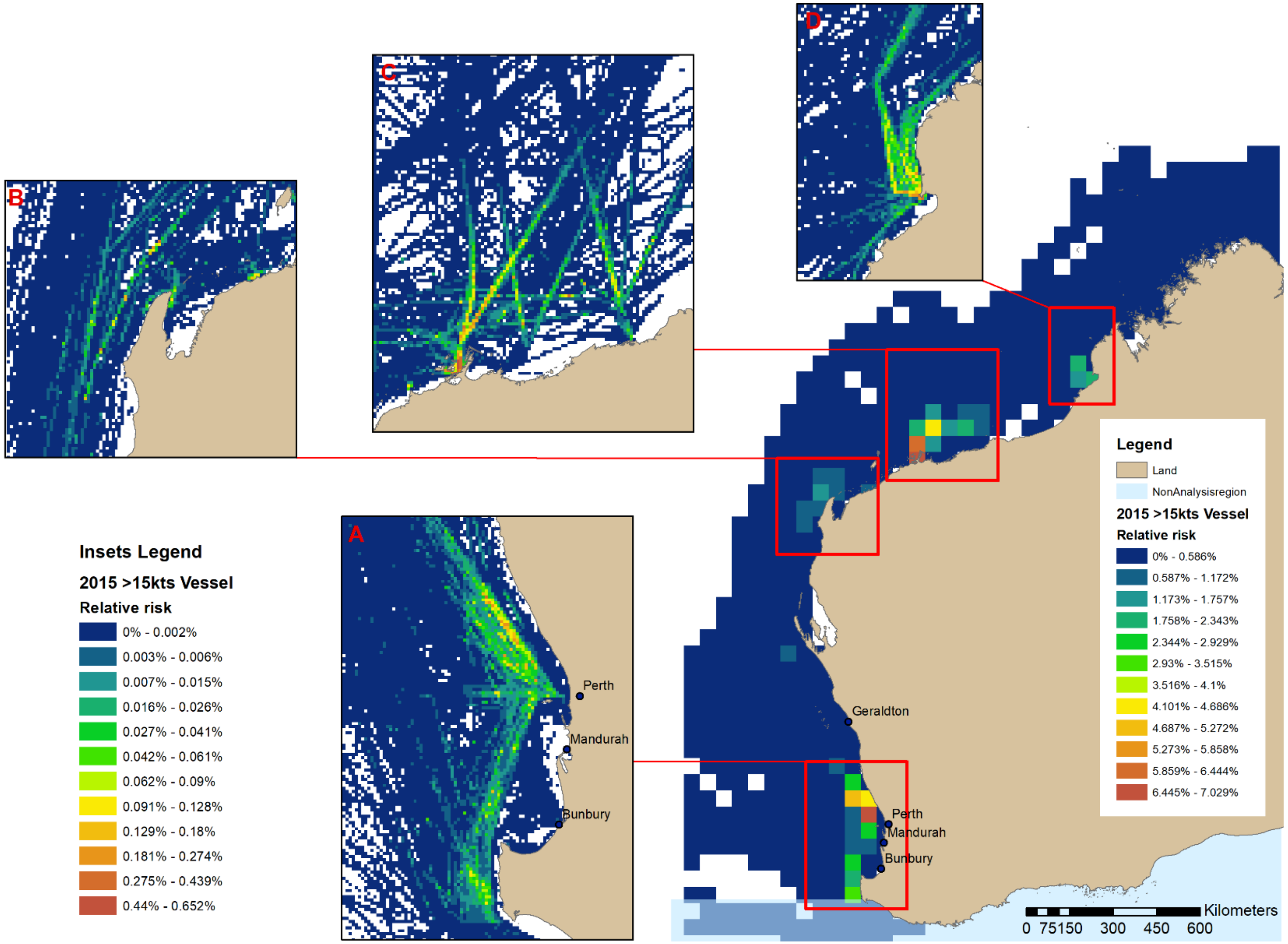


Figure 34 Relative risk of a collision between West coast Humpback whales and fast moving (>15knots) AIS equipped vessels in 2015, for the combined Northern and Southern migration

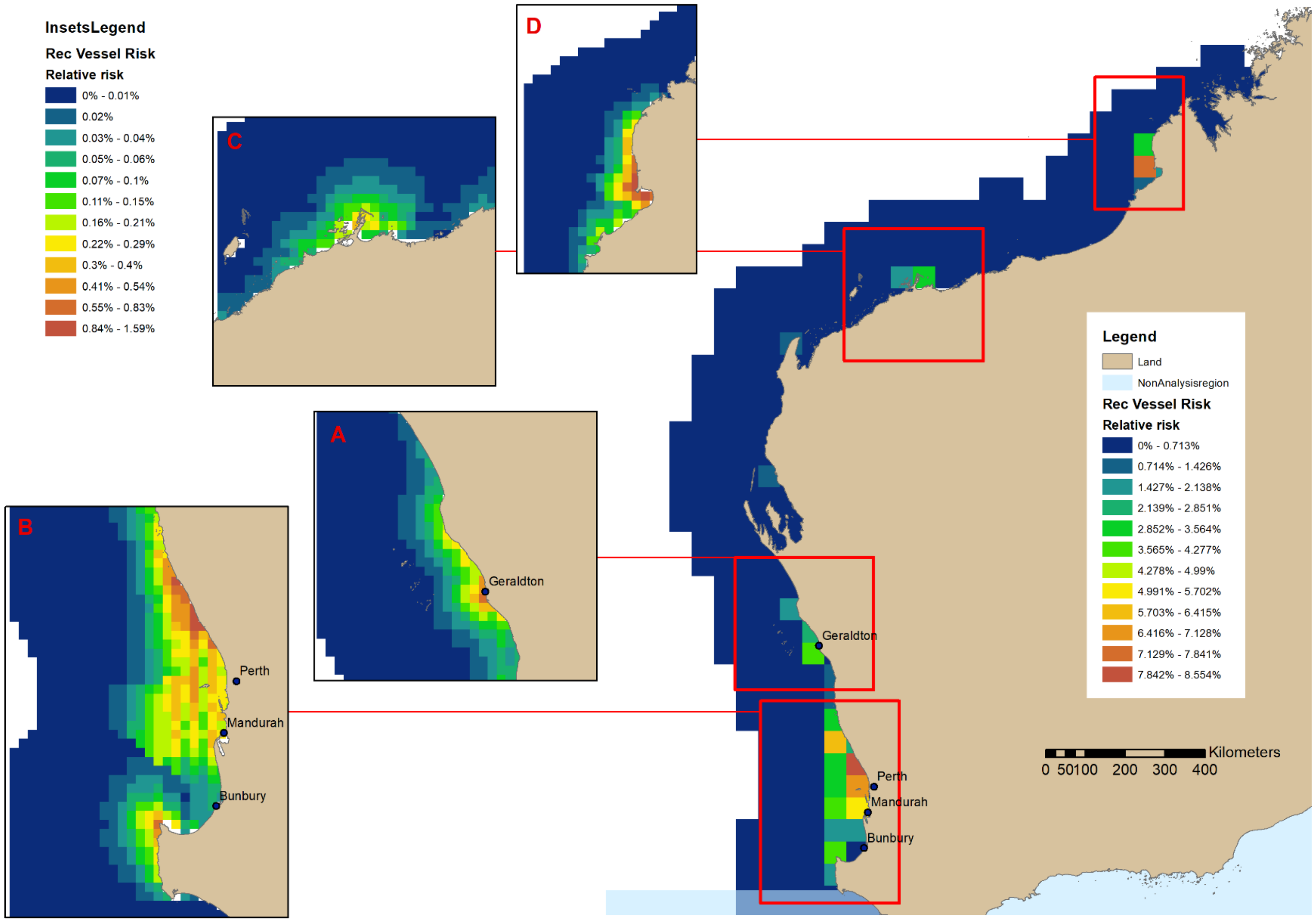


Figure 35 Relative risk of co-occurrence between West coast Humpback and recreational vessels, for the combined Northern and Southern migration

Once we have the spatial maps of relative risk, we can also look at risk totals to compare the Southern to Northern migration for the various vessel data sets (Figure 36). The risk 2013-2015 has increased in most of the vessel data sets. To examine if this is simply due to an increase in vessel numbers (or km travelled in each cell) or if there is a change in the location of vessel traffic relative to whales, we can look at standardised average risk per vessel km (Figure 37). Once standardised, it can be seen that it is likely that a change in vessel spatial distribution is not responsible for the increase in risk but rather it is simply a result of increases in vessel numbers over time.

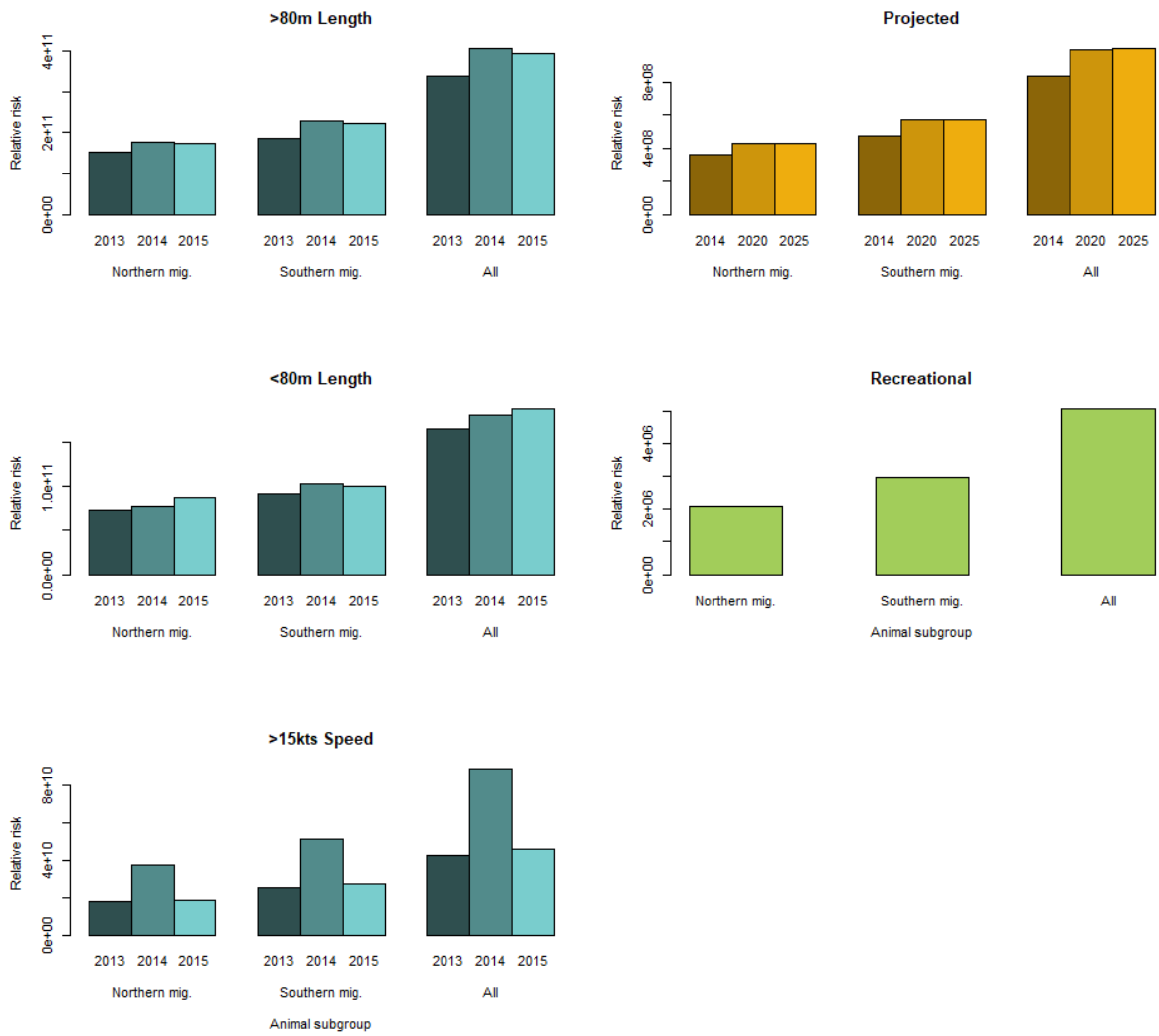


Figure 36 Total relative risk (using the relevant risk metric described in Table 10) for various vessel sources for West coast Humpback whales, over the combined Northern and Southern migrations.

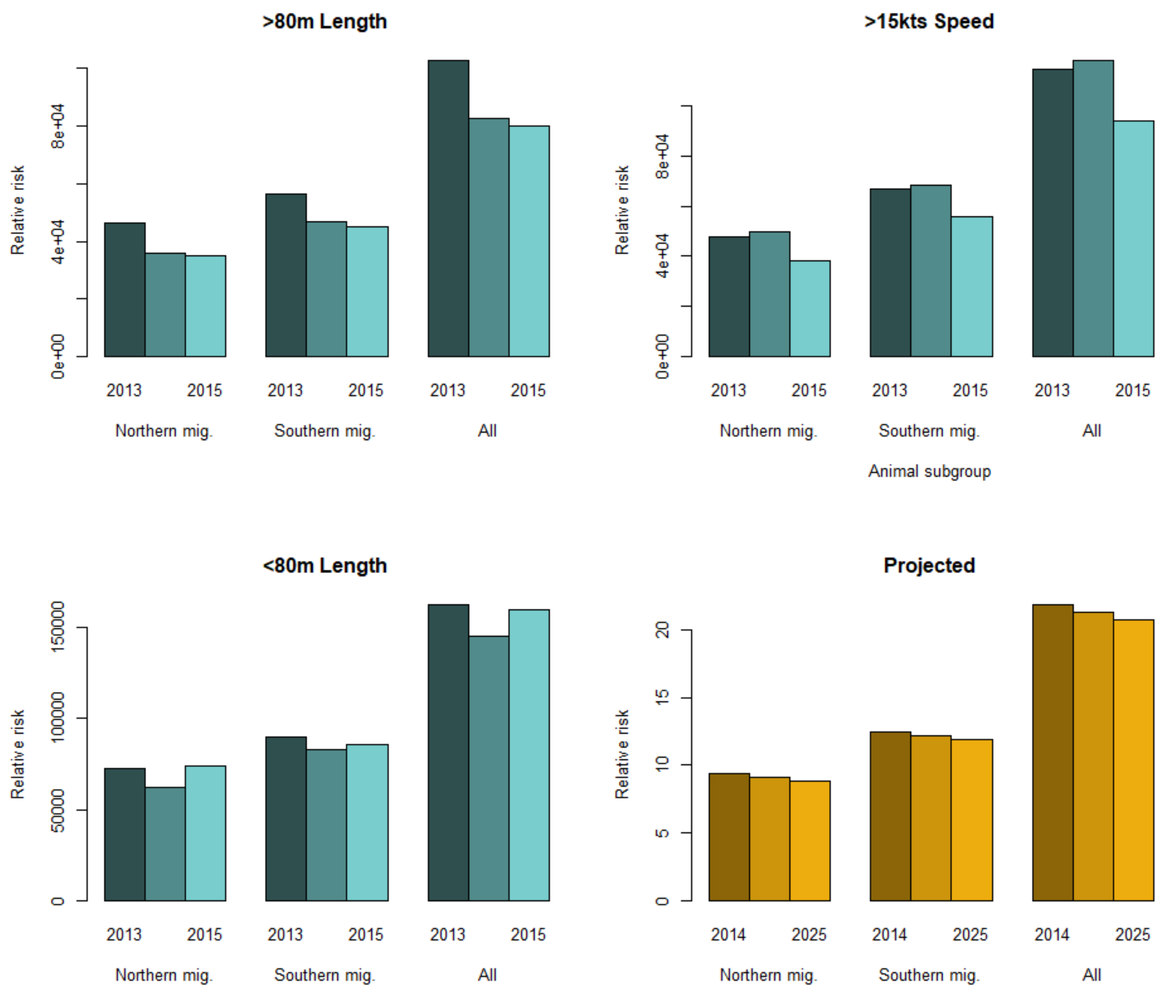


Figure 37 Total relative risk per vessel km (using the relevant risk metric described in Table 10) for various vessel sources for West coast Humpback whales, over the combined Northern and Southern migrations. By standardising per vessel km, we can see if any change in relative risk is due to changes in the amount of vessel traffic, or changes in vessel distribution.

It is also possible to compare the relative risk between specific areas, for example we can compare the aggregations/resting areas (Figure 38) and obtain relative risk for each area (Figure 39). Since the areas are of different sizes, it may make sense to standardise by area size (Figure 40).

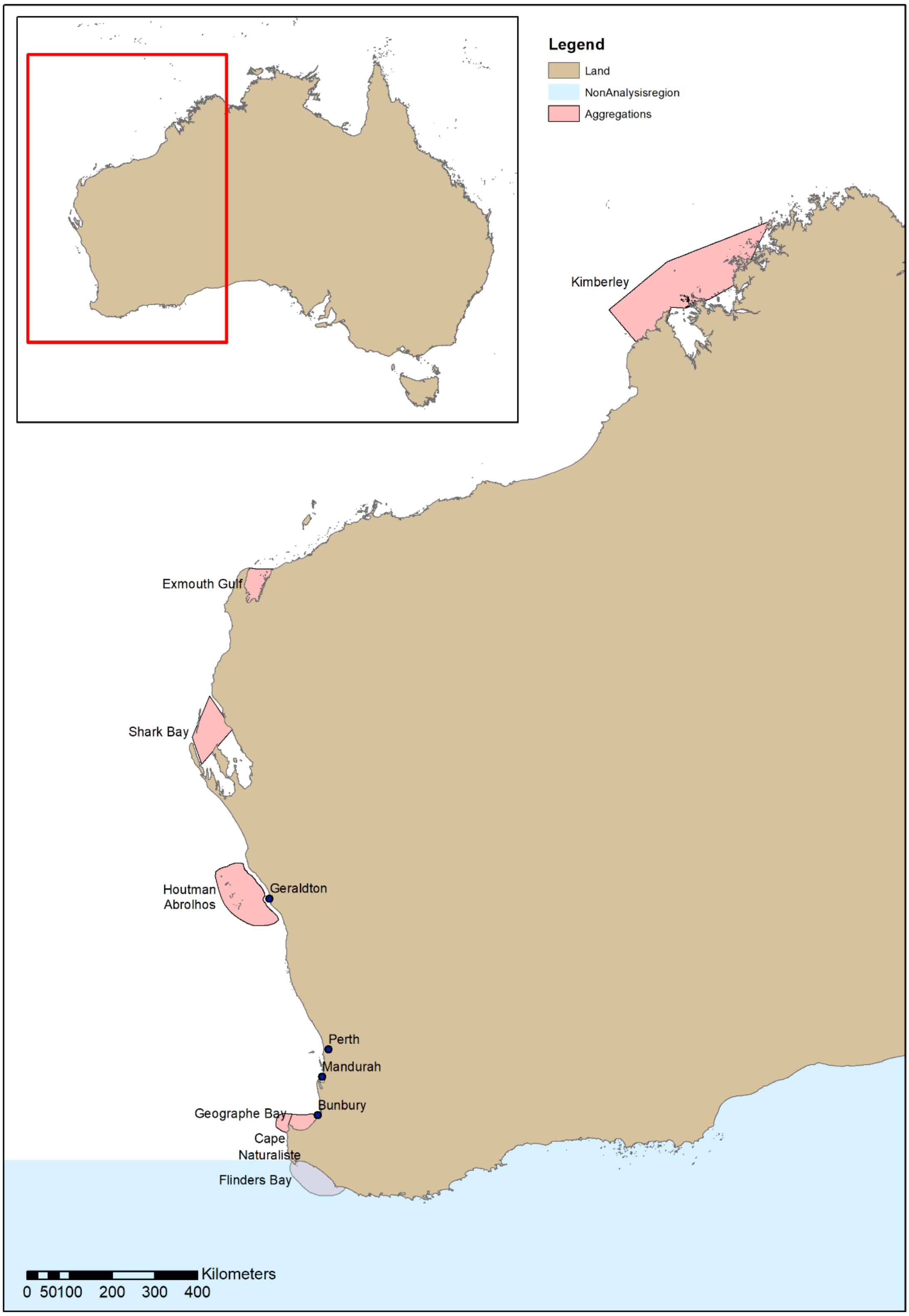


Figure 38 Location of West coast humpback aggregations/resting areas (Biological Important Areas as provided by DOEE 2015)

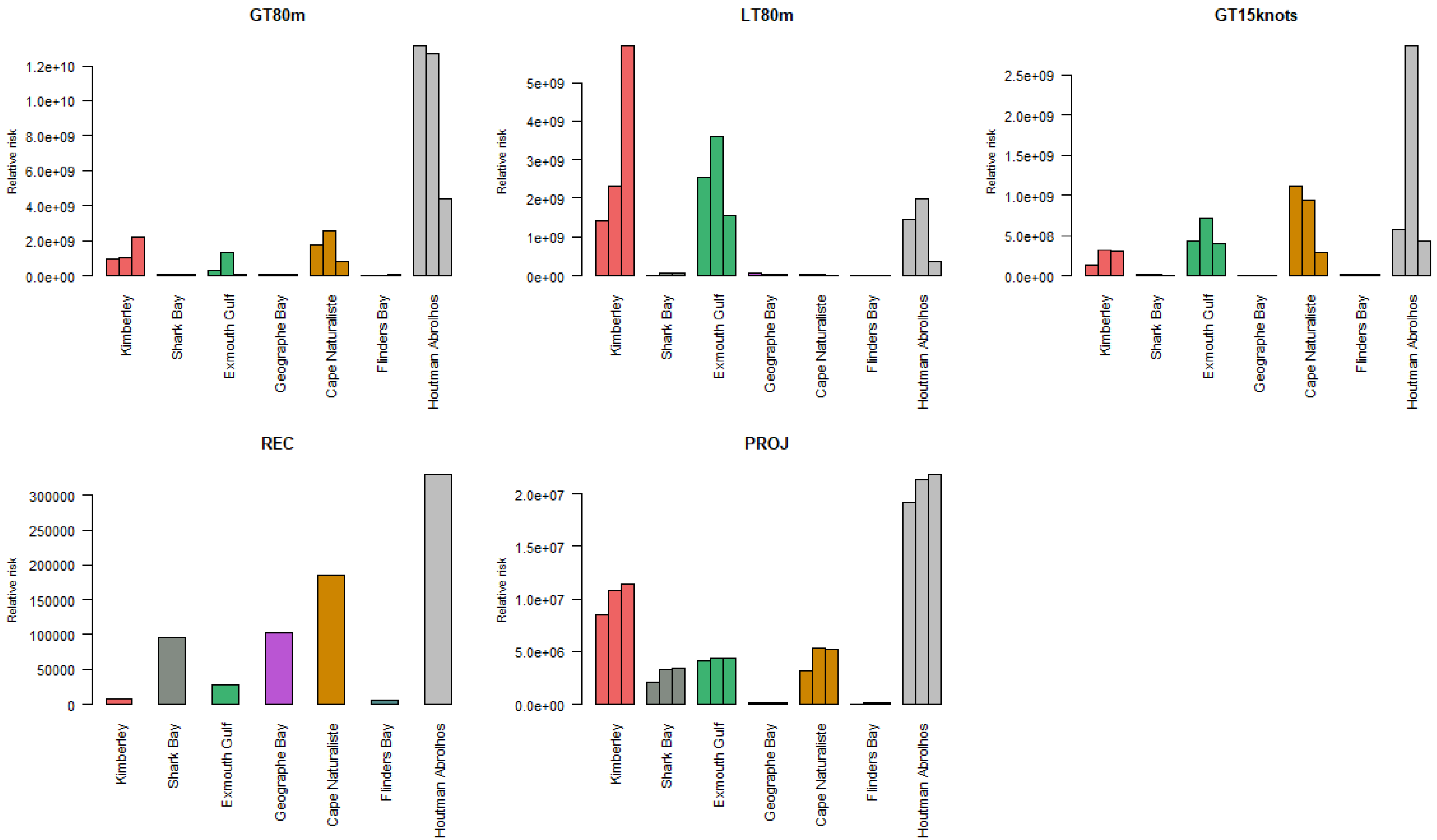


Figure 39 Total relative risk (using relevant risk metrics as per Table 10) at each West Australian humpback aggregation/resting area (each bar is a year left to right 2013, 2014, and 2015), for the combined Northern and Southern migrations.

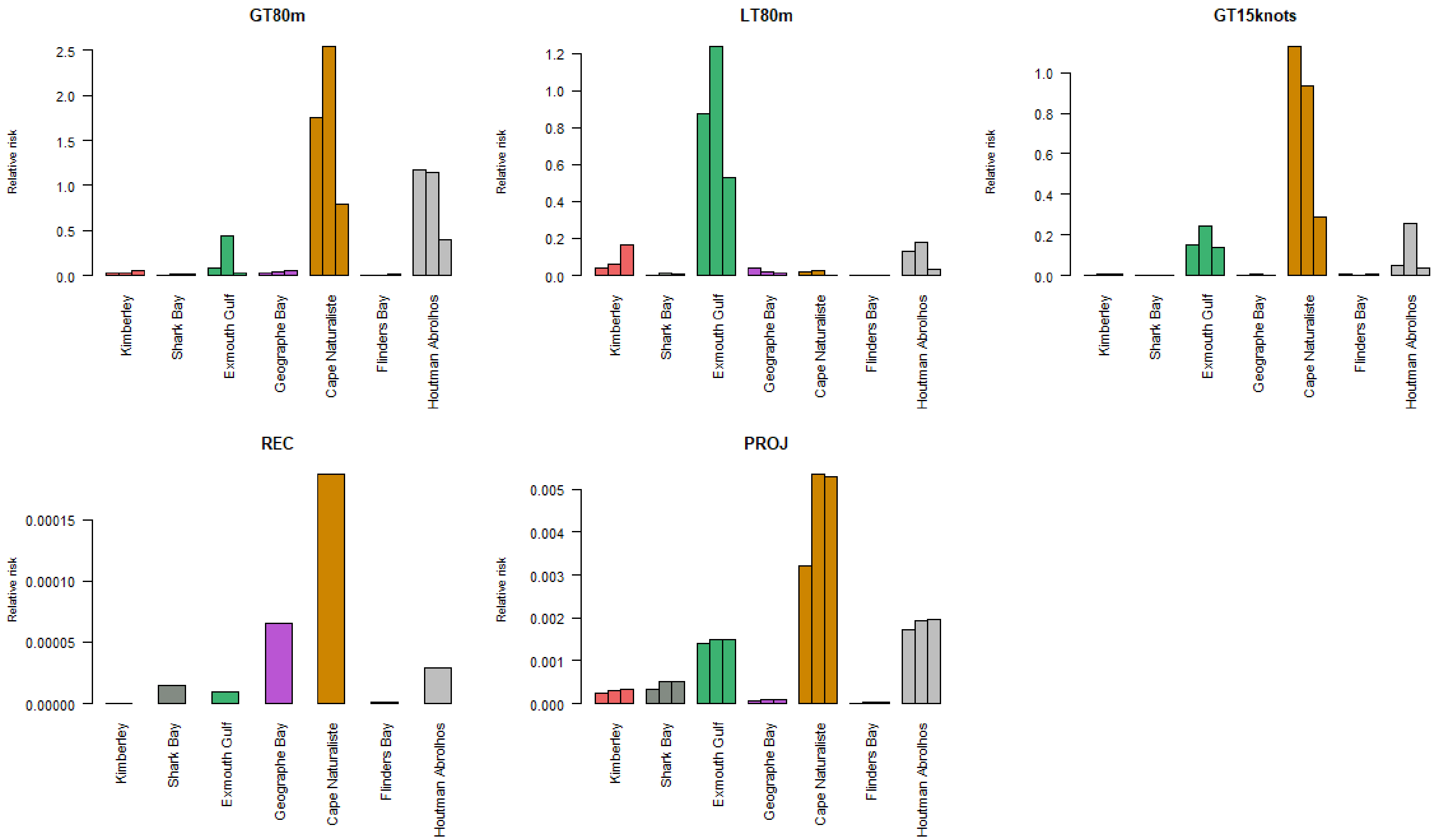


Figure 40 Total relative risk (using relevant risk metrics as per Table 10) at each West Australian humpback aggregation/resting area standardised by area size (each bar is a year left to right 2013, 2014, and 2015), for the combined Northern and Southern migrations.

7.1.3 Assumptions and caveats

Assumptions 10 Assumptions and caveats for risk analysis of Western Australian humpback whales

The following assumptions were made:

- Tag model assumptions as per Section 4.4. In particular, this means that the risk maps indicate risk for a population behaving as per the tagged subset of the population. Specifically, if there are sub-groups within the population that were not captured by the tagging sample regime, then these animals will be under-represented in the risk. For example, if no animals that utilise a certain resting area were sampled, this resting area will not be represented in the risk map.

- AIS assumptions and caveats as per Section 5.1.4. The main repercussions of these assumptions for the risk maps are:

    - The smaller vessels are less represented in the AIS data. Therefore, the <80m vessel risk maps will not be representative of the risk from all vessels <80m but only a subset of those.

- Risk Metric assumptions as per Section 3.2.3

As well as these assumptions/caveats, we also assumed that the number of animals migrating North equals the number returning South as this allowed us to easily provide a total risk by adding the two risk measures.

The aggregation areas provided by DoEE are part of the work for Biologically Important Areas of Regionally Significant Marine Species. A complete list of caveats and restrictions related to these data is available at the link below[10].

[10] Available at: http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B2ed86f5a-4598-4ae9-924f-ac821c701003%7D

7.1.4 Discussion/Summary

Conclusion F Conclusions for Western Australian Humpback Whales

Interestingly, we found the Southern migration to have a slightly higher relative risk than the Northern migration. However, this is not conclusive due to the assumptions and need for model validation and requires further investigation.

Based on the preliminary analysis we found:

Larger size (>80m) AIS equipped vessels

The area of higher relative risk is **Dampier to Port headland** (Figure 32).

Smaller size (<80m) AIS equipped vessels

For smaller AIS equipped vessels, the areas around **Exmouth, Dampier, Port Headland, and Broome** showed higher relative risk (Figure 33).

Fast moving (>15kts) AIS equipped vessels

Indications were **Dampier, Augusta to Perth, and Broome** were of highest relative risk (Figure 34).

Recreational vessels

For recreational vessels risk, as expected, was correlated to population centres e.g., **Augusta to Perth, Geraldton, and Broome** (Figure 35).

Aggregation/resting area comparison

Comparing resting areas, **Cape Naturaliste** and **Houtman Abrolhos** appeared to have the highest relative risk (Figure 36 and Figure 37).

Recommendations to improve risk analysis

- A new method has been developed to obtain distributions from tag movement data. This model and analysis would benefit from further refinement and ground-truthing/validation against existing survey/sighting data. Peer-review and publication of the methodology would also be beneficial.
- Gathering more information on parameters such as surface/dive behaviour and behavioural response (immediate vicinity of vessels and broadscale with respect to shipping lanes)

7.2 Eastern Australian Humpback population

7.2.1 Data source

To develop a humpback whale distribution model for the east coast of Australia, humpback whale sighting datasets were identified and assessed for their suitability of inclusion in a predictive spatial habitat model. Many datasets available for the entire coast consisted of relatively clustered sighting data from land-based population surveys (e.g., Point Lookout, QLD, Byron Bay, NSW, and Cape Solander, NSW), with the exception of the Great Barrier Reef, QLD in which the distribution of the breeding grounds has been well surveyed (Smith et al. 2012, Peel et al. 2015).

There is not a single dataset/model that covers the whole East coast population. So currently the analysis consists of 3 separate analyses with coverage as per Figure 41.

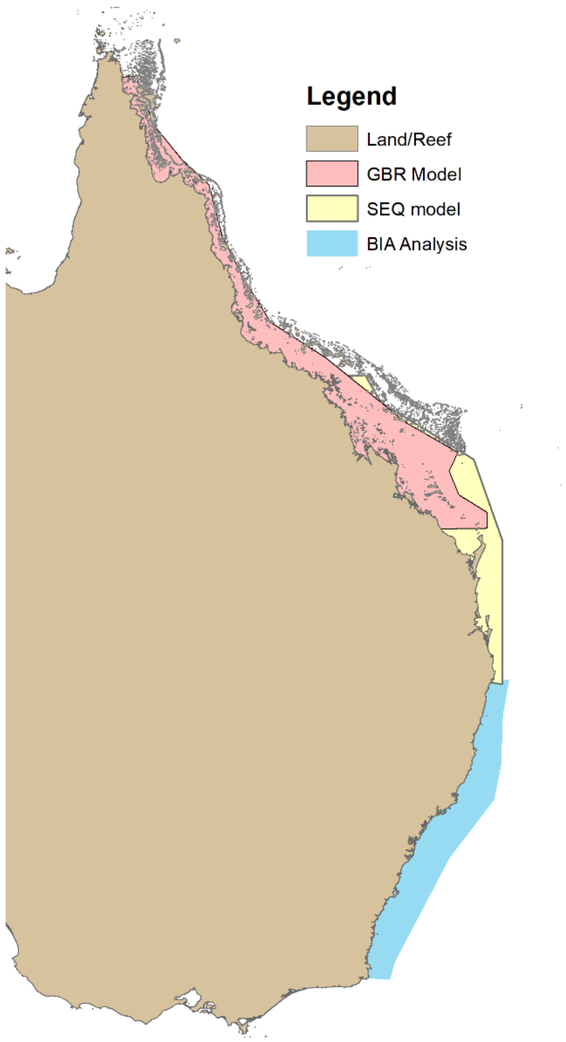


Figure 41 Summary of the locations of the separate analyses for each component of the East coast Humpback population (GBR = Great Barrier Reef model, SEQ= South-east Queensland model and BIA= Biological Important Areas).

Great Barrier Reef model (GBR)

We have good spatial distributions for the majority of the GBR region as per Smith et al. 2012, and Peel et al. 2015 (Figure 42 and Figure 43), except for an area around the Capricorn/Bunker Group in the Southern GBR region.

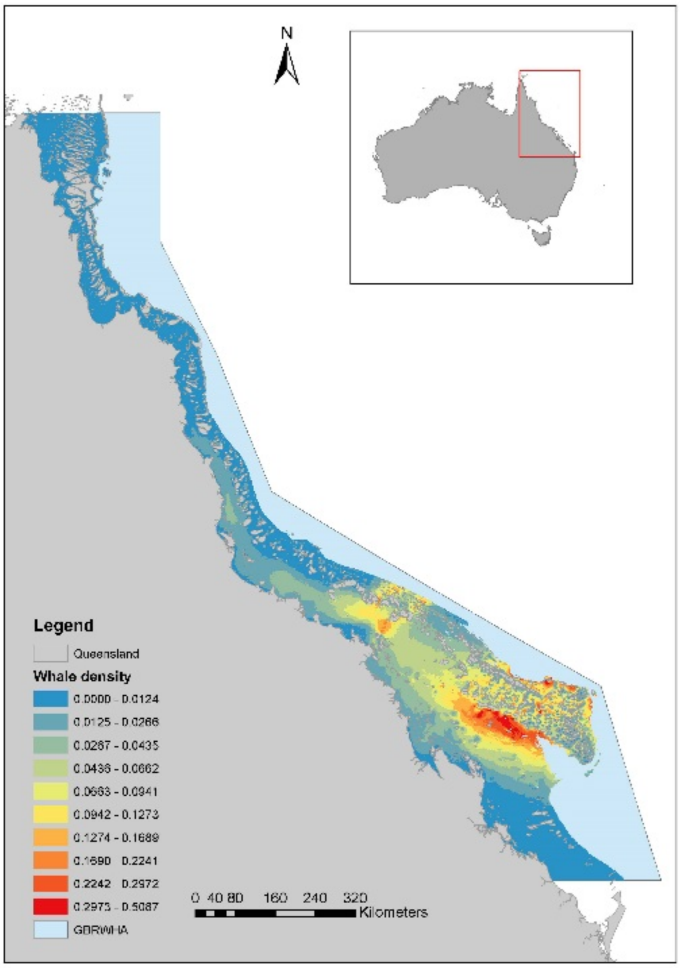


Figure 42 East coast humpback whale GBR habitat model for all animals, including adult and calf groups (Smith et al. 2012, Peel et al. 2015).

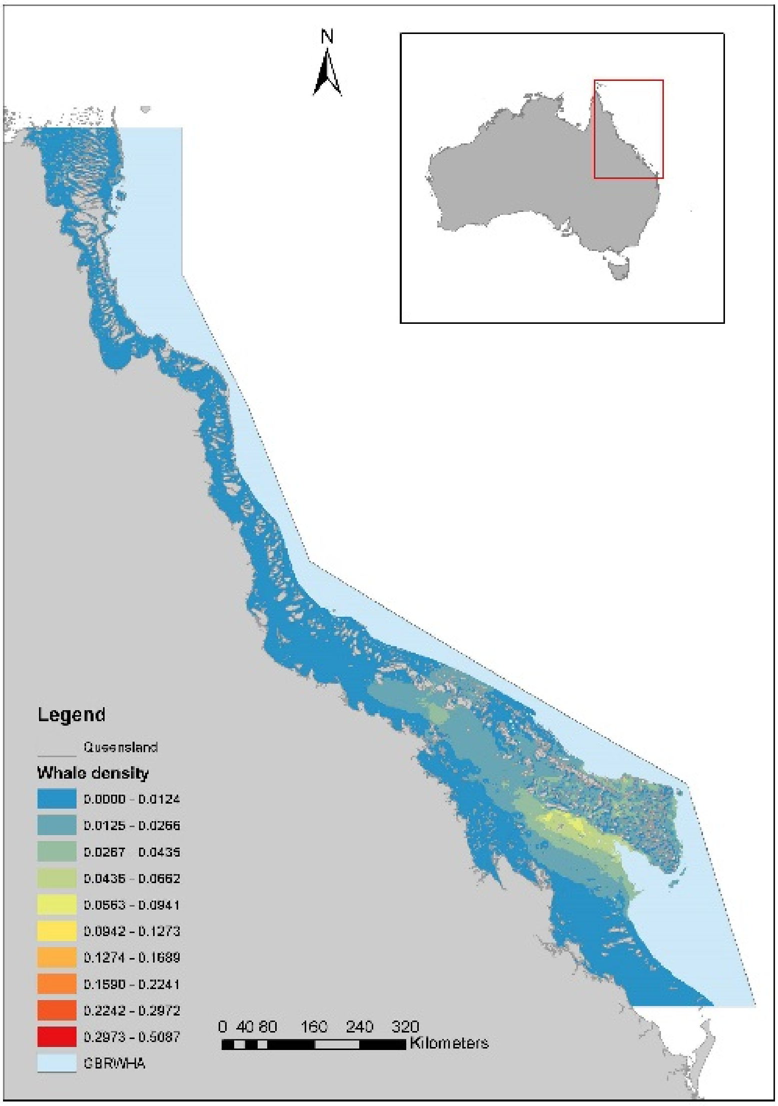


Figure 43 East coast humpback whale GBR habitat model for groups with calves (Smith et al. 2012, Peel et al. 2015).

Southern Queensland model (SQ)

The Southern Queensland coast has not been covered by aerial surveys as for GBR region and therefore the development of a distribution model would have to use alternative data sources. Sufficient data was available from the satellite tracking data collected by the AMMC in 2009. This is the same data that had been used as validation data of the breeding ground predictive habitat model in Smith et al. (2012).

Using the same new method as developed for West coast humpback whales (Section 7.1.1), we can obtain an interpolated distribution (Figure 44). One item of note is that unrealistically high densities on the coast in the North-West of Figure 44 due to issues with simulation at bounds. This is a present limitation of this approach and further development of methods is required to adjust for this or alternatively, the collection of more tag data would help.

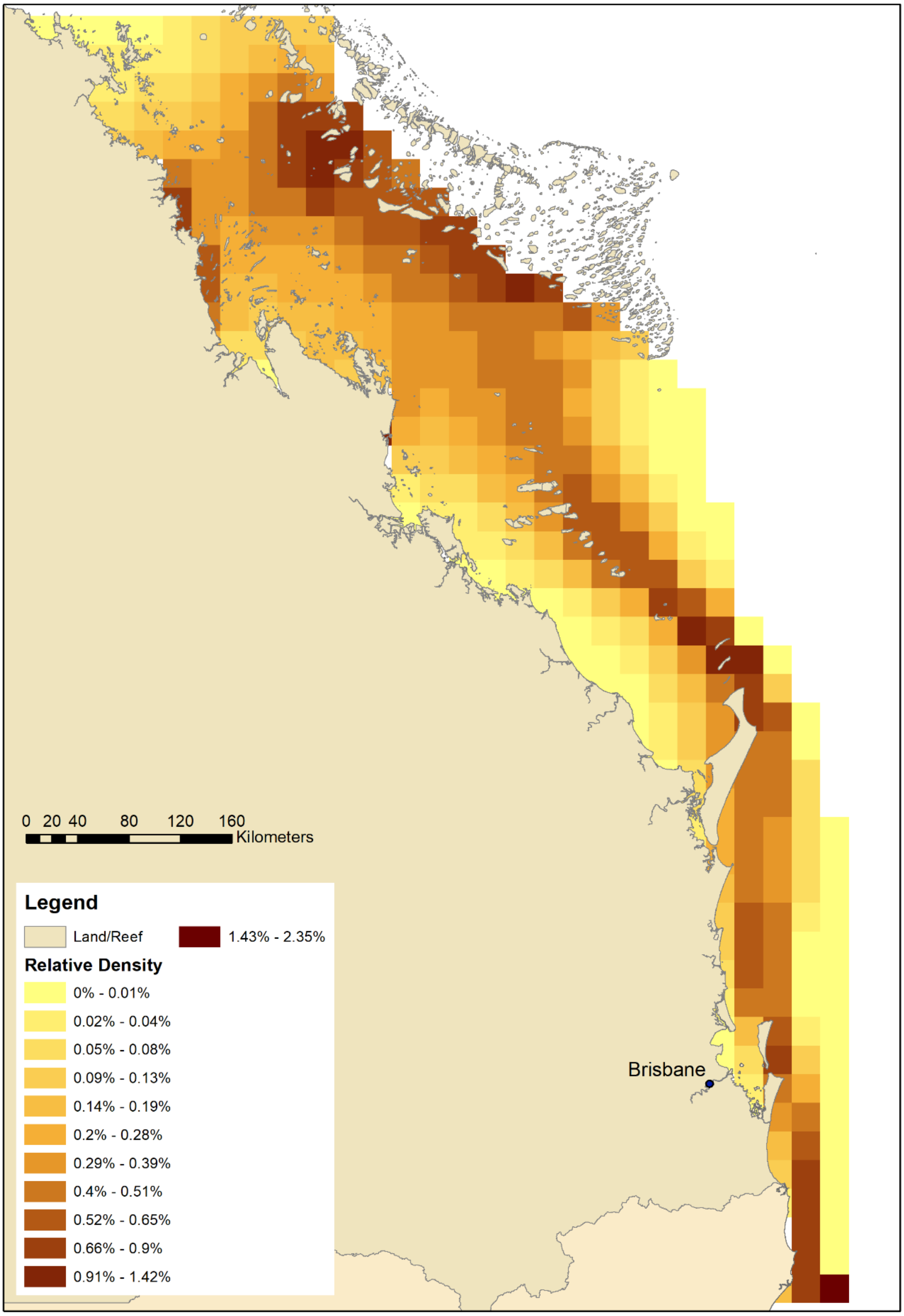


Figure 44 Distribution of humpback whales for SEQ areas based on tag movement data model.

NSW/whole East coast Biological Important Areas (BIA)

We do not have a complete spatial density for the areas outside Queensland for the East Coast humpback population. Therefore, we used polygons of extent from BIA information (DoEE 2015) as per Figure 45.

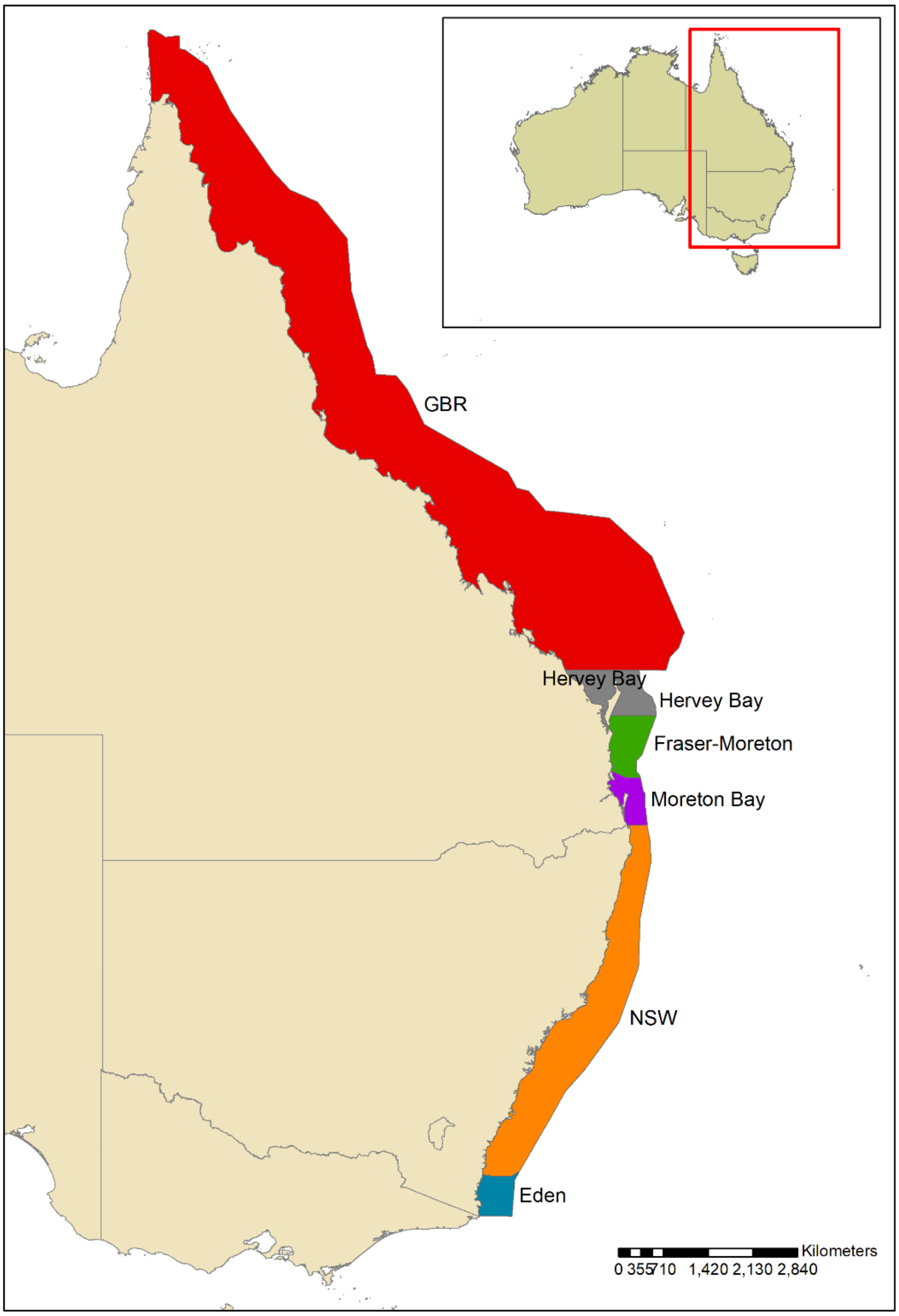


Figure 45 East coast humpback whale species distribution from BIA (DOE 2015)

7.2.2 Risk maps - Great Barrier Reef Marine Park

The GBR animal distribution models were used in conjunction with the AIS data density and recreational boat model to produce various risk maps (see Table 11).

Table 11 Summary of data sources and mapping for Australian East coast GBR Humpback whales

Whale Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps	Figures
Spatial/Habitat model (Section 4.1) for all groups, adult groups and calf groups Source: GBR spatial model (2012 & 2014) See Section 7.2.1	Vessels ≥80m Length	2013-2015 AIS Data (See Section 5.1)	Per season (Aug-Sep) 2013-2015 (only 2015 shown in this report)	1/30° 1/2°	Relative risk of a fatal collision (See Section 3.2.1)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 46 Figure 50
	Vessels <80m Length				Relative risk of a collision[1] (See Section 3.2.2)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 47
	Vessels >15kts speed				Relative risk of a collision[1] (See Section 3.2.2)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 48
	Recreational Vessels	See Section 5.2	Single hypothetical season	1/10 °	Relative co-occurrence	Core area (at 1/2°) and Higher risk areas (at 1/10°)[2]	Figure 49

[1] For vessels less than 80m we are less sure if the probability of fatality curves are relevant so we only calculated risk of collision.
[2] As the recreational vessel model has much greater uncertainty we examine at larger grid size than the AIS data.

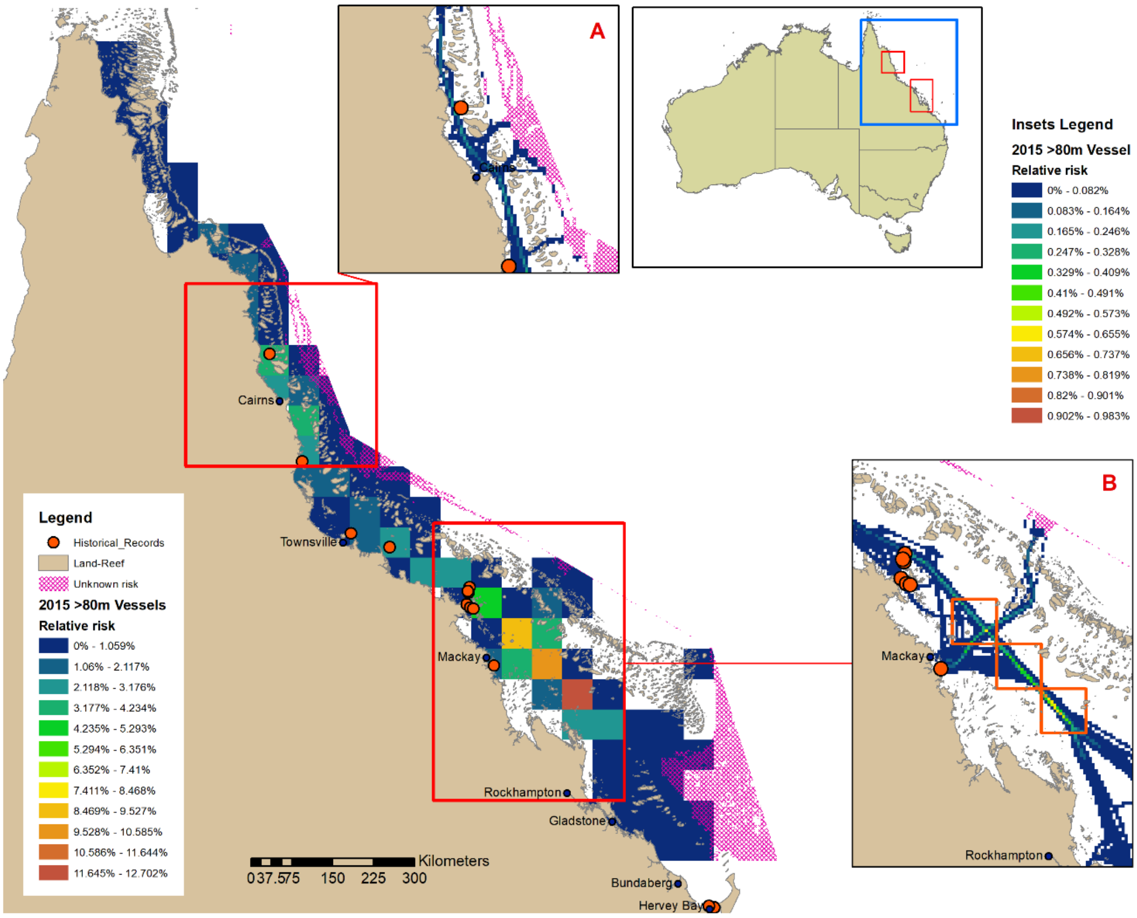


Figure 46 Relative risk of a fatal collision between humpback whales (all groups) in the Great Barrier Reef and large (>80m in length) AIS equipped vessels, with historical vessel strike locations shown (red circles). The purple hash denotes area that were not surveyed in the study region that contain vessel traffic so the risk is unknown. Where unsurveyed area partially overlaps with a grid cell grid cell risk extrapolated from model for whole cell.

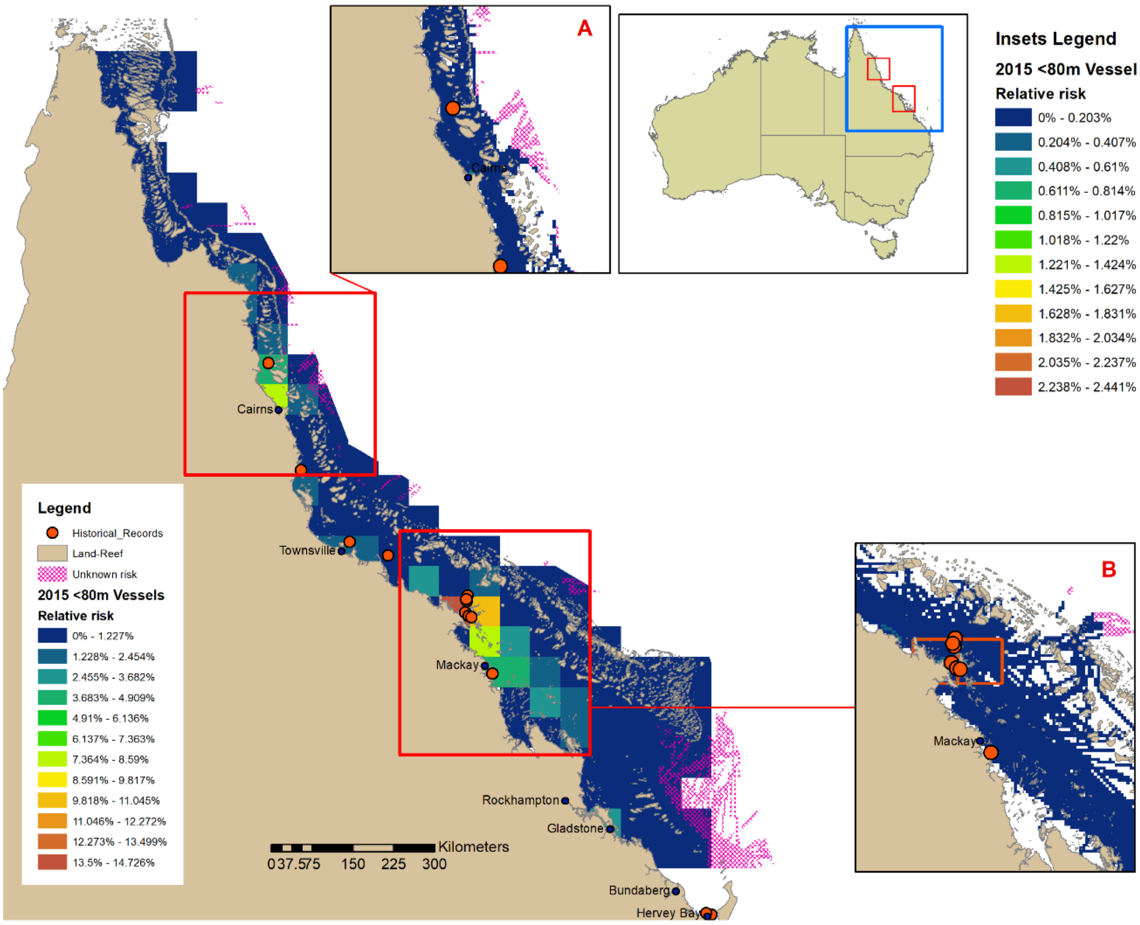


Figure 47 Relative risk of a collision between humpback whales (all groups) in the Great Barrier Reef and small (<80m in length) AIS equipped vessels, with historical vessel strike locations shown (red circles). The purple hash denotes area that were not surveyed in the study region that contain vessel traffic so the risk is unknown.

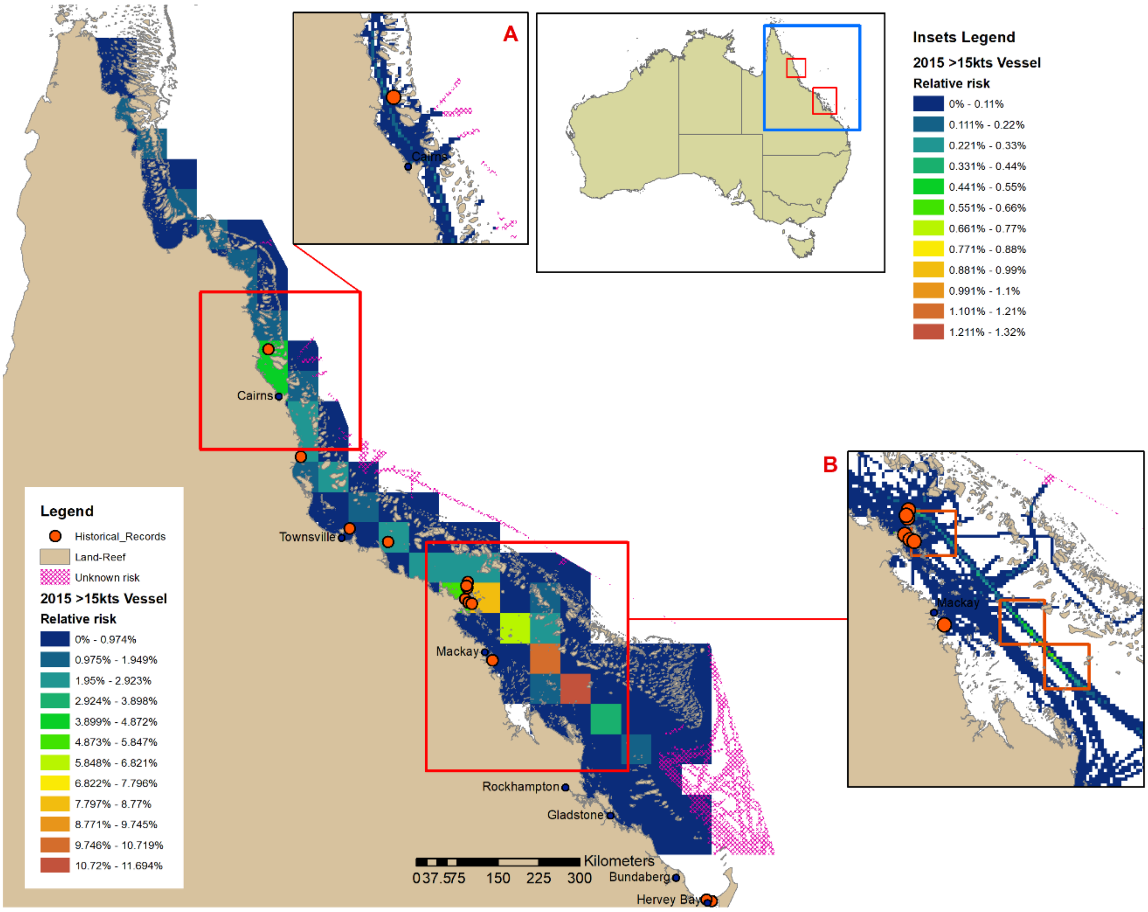


Figure 48 Relative risk of a collision between humpback whales (all groups) in the Great Barrier Reef and fast moving (>15kts in speed) AIS equipped vessels, with historical vessel strike locations shown (red circles). The purple hash denotes area that were not surveyed in the study region that contain vessel traffic so the risk is unknown.

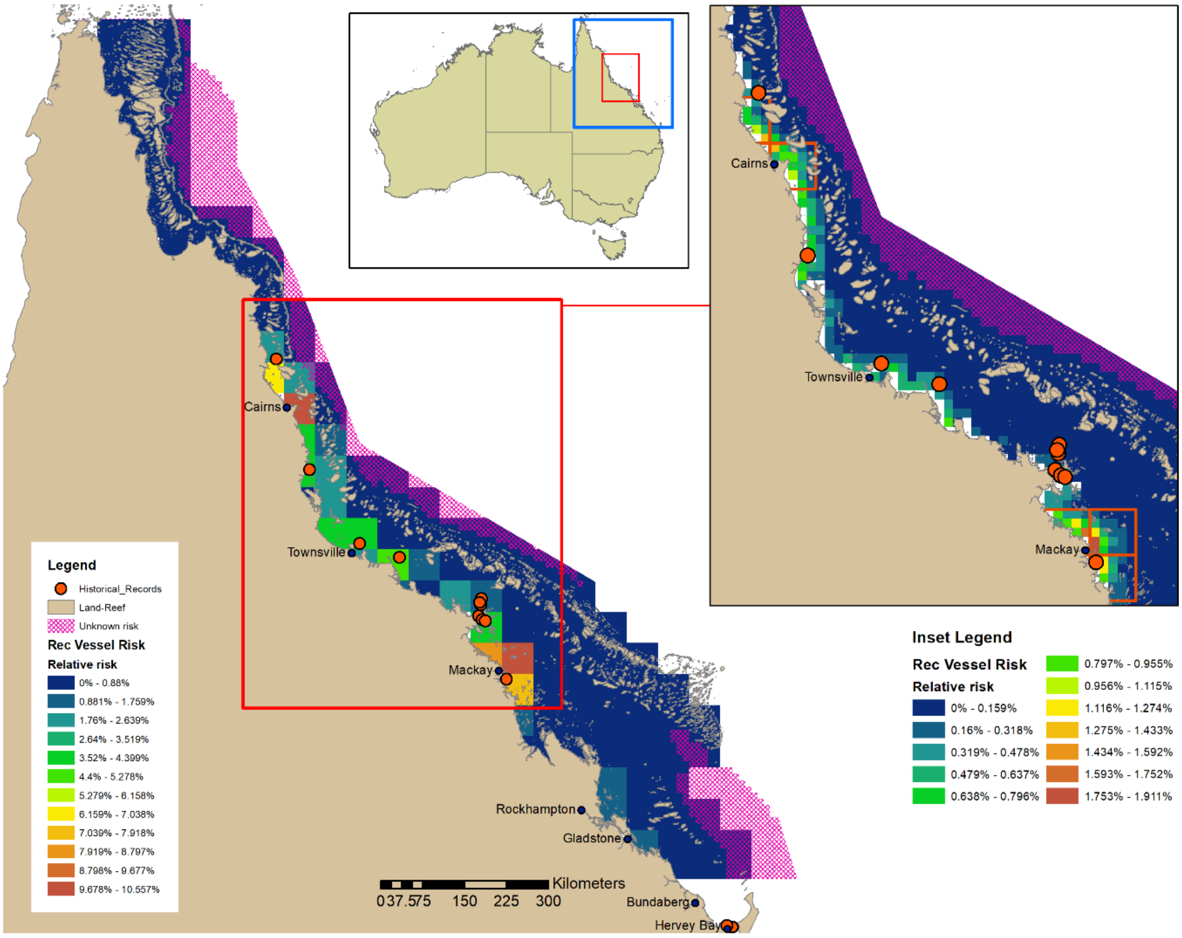


Figure 49 Relative risk of co-occurrence of humpback whales (all groups) in the Great Barrier Reef and recreational vessels, with historical vessel strike locations shown (red circles). The purple hash denotes area that were not surveyed in the study region that contain vessel traffic so the risk is unknown.

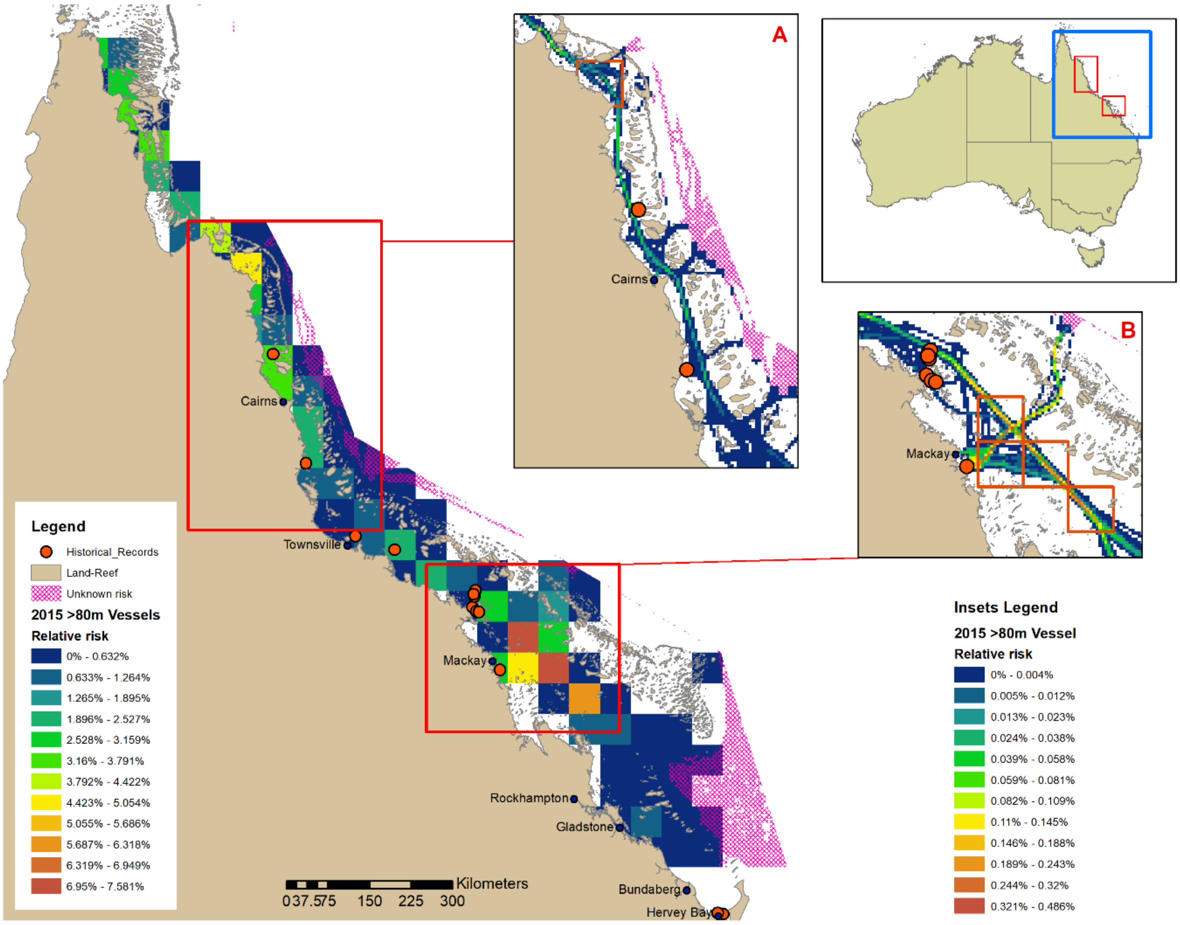


Figure 50 Relative risk of a fatal collision between calf groups of Humpback whales in the Great Barrier Reef and large (>80m in length) AIS equipped vessels, with historical vessel strike locations shown (red circles). The purple hash denotes area that were not surveyed in the study region that contain vessel traffic so the risk is unknown.

The GBR spatial model provides a distribution of all humpback whales, but also separate distributions for adult groups and mother calf groups. Therefore, we can also produce risk maps for these sub- groups (e.g., Figure 50).

We can look at the total risk and make comparisons between calf and adult groups (Figure 51). The overall total risk is highest for adult groups. However, this is due to the larger number of adult groups. If we can look at the same plots standardised per whale (Figure 52) then on a risk per whale basis calf groups are at higher risk. Since the parameters for other factors that affect vessel strike risk (e.g. surface availability, collision avoidance) are not differentiated between the groups in the model then this risk difference is solely due to the difference in spatial distribution of calf and adult groups.

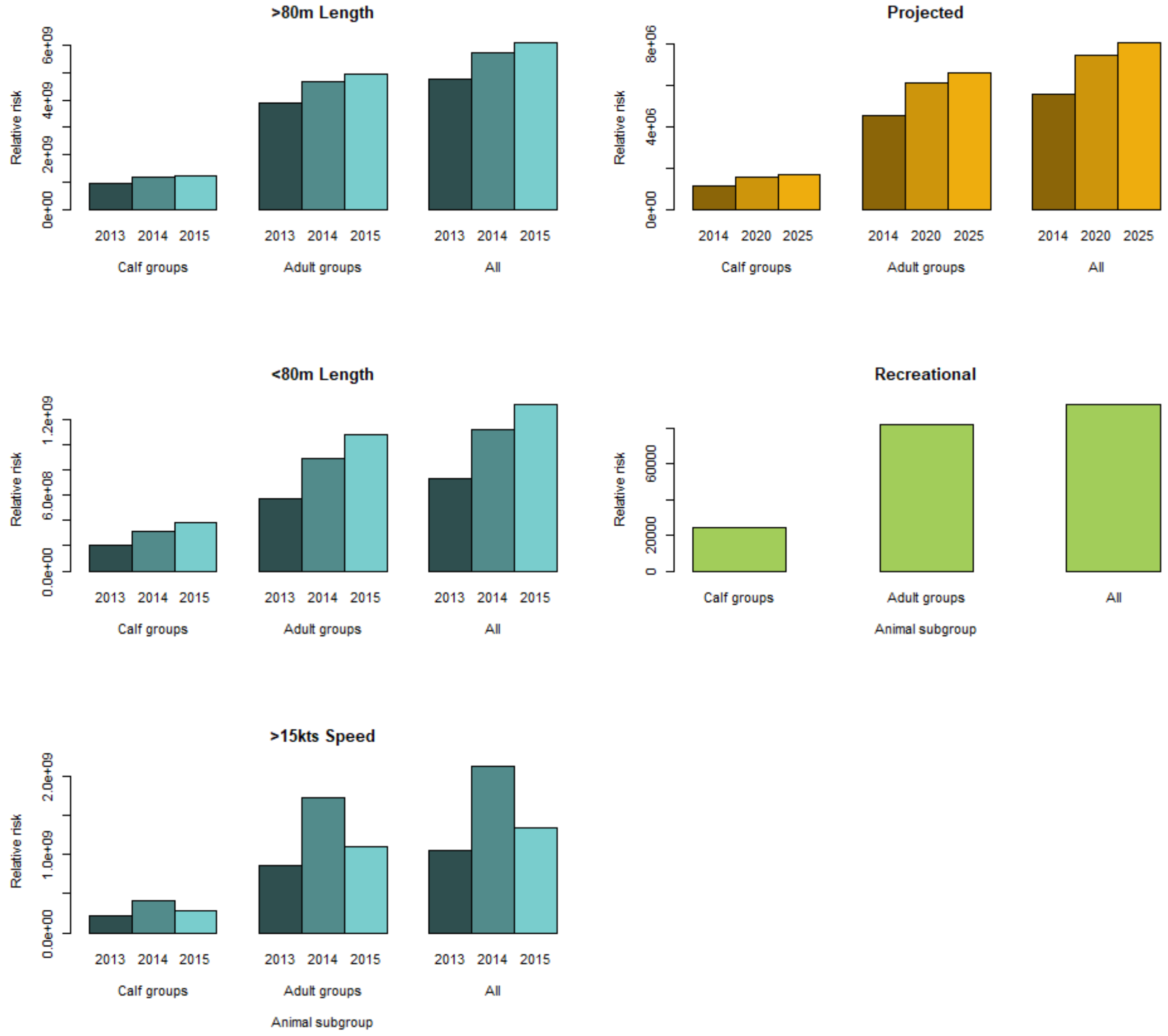


Figure 51 Total relative risk (using relevant risk metric described in Table 11) by whale sub-groups, for each vessel source, over the years 2013-2015, assuming an annual increase of 10.5% annual whale population increase.

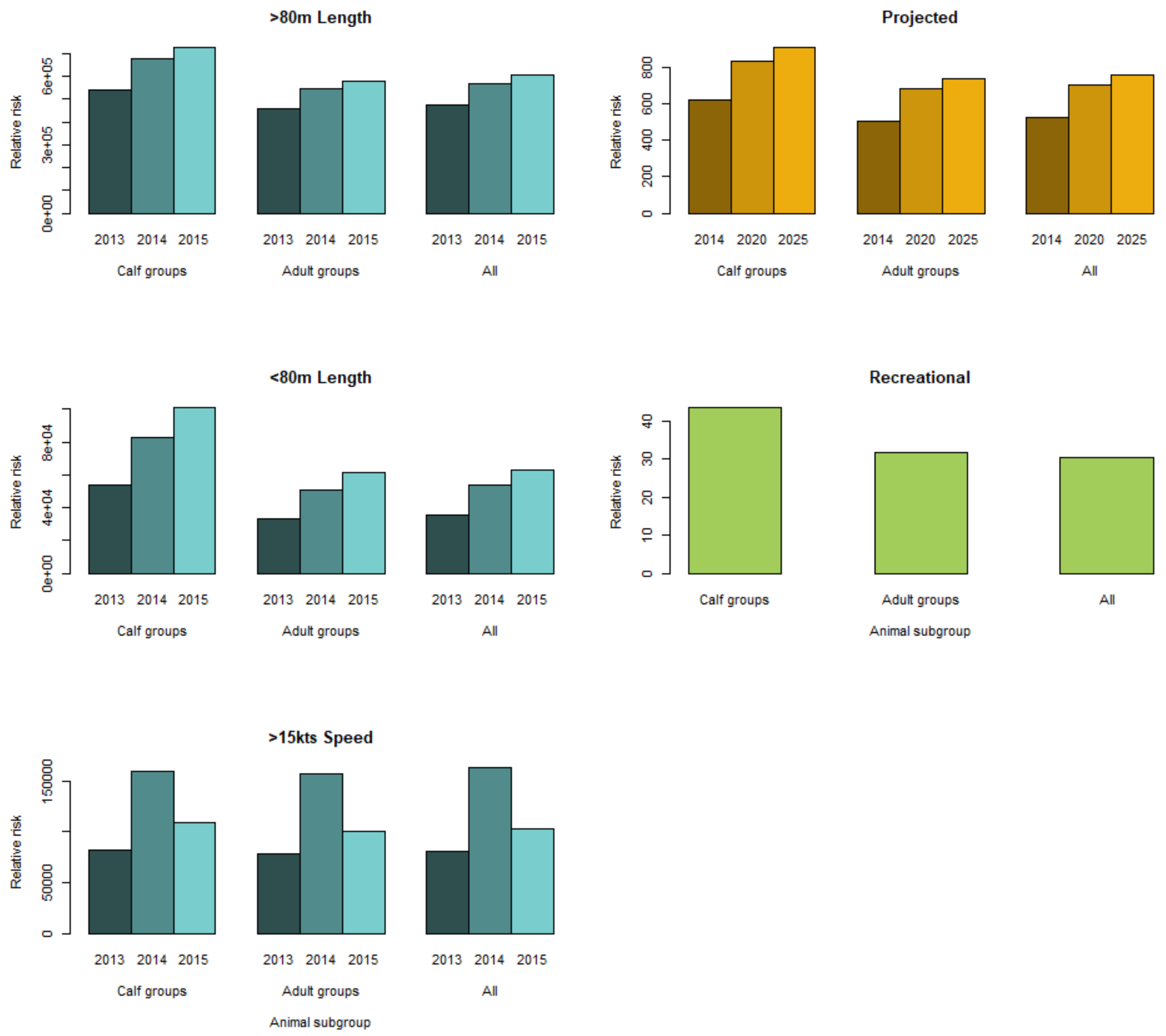


Figure 52 Total relative risk per whale (using relevant risk metric described in Table 11) by whale sub-groups, for each vessel source, over the years 2013-2015, assuming an annual increase of 10.5% annual whale population increase. By standardising per whale we take into account that there are more adult groups than calf groups.

7.2.3 Risk maps - Southern Queensland

The SEQ tag movement model was used in conjunction with the AIS data density and recreational boat model to produce various risk maps (see Table 12).

Table 12 Summary of data sources and mapping for Australian East coast SEQ Humpback whales

Whale Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps	Figures
Tag movement model (Section 4.2) Source: SEQ Tag model (See Section 7.2.1)	Vessels ≥80m Length	2013-2015 AIS Data (See Section 5.1)	Per season (Aug-Sep) 2013-2015 (only 2015 shown in this report)	1/30° 1/2°	Relative risk of a fatal collision (See Section 3.2.1)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 53
	Vessels <80m Length				Relative risk of a collision[13] (See Section 3.2.2)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 54
	Vessels >15kts speed				Relative risk of a collision[13] (See Section 3.2.2)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 55
	Recreational Vessels	See Section 5.2	Single hypothetical season	1/10 °	Relative co-occurrence	Core area (at 1/2°) and Higher risk areas (at 1/10°)[14]	Figure 56

[13] For vessels less than 80m we are less sure if the probability of fatality curves are relevant so we only calculated risk of collision.
[14] As the recreational vessel model has much greater uncertainty we examine at larger grid size than the AIS data.

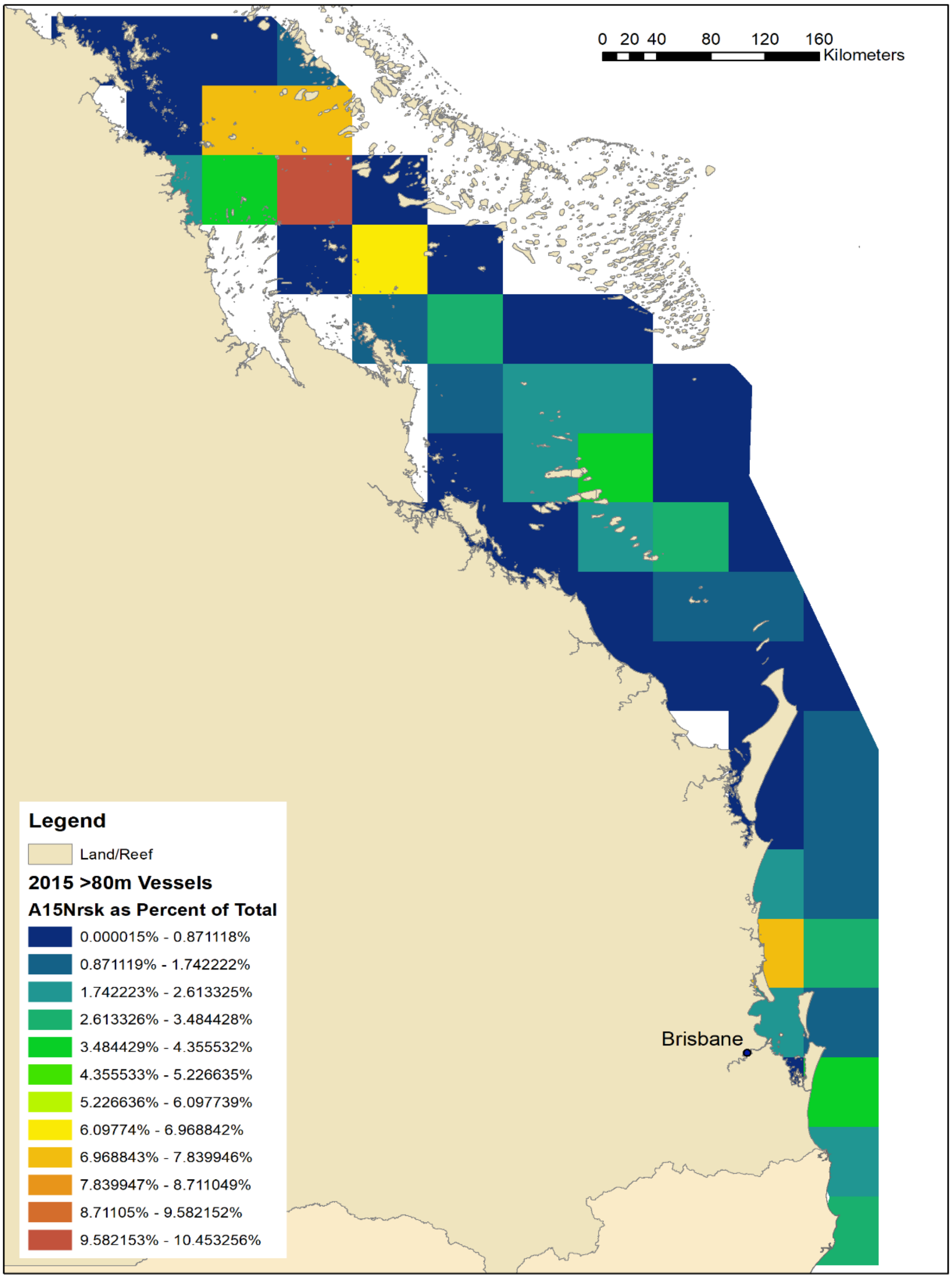


Figure 53 Relative risk of a fatal collision between humpback whales in SEQ with large (>80m in length) AIS equipped vessels

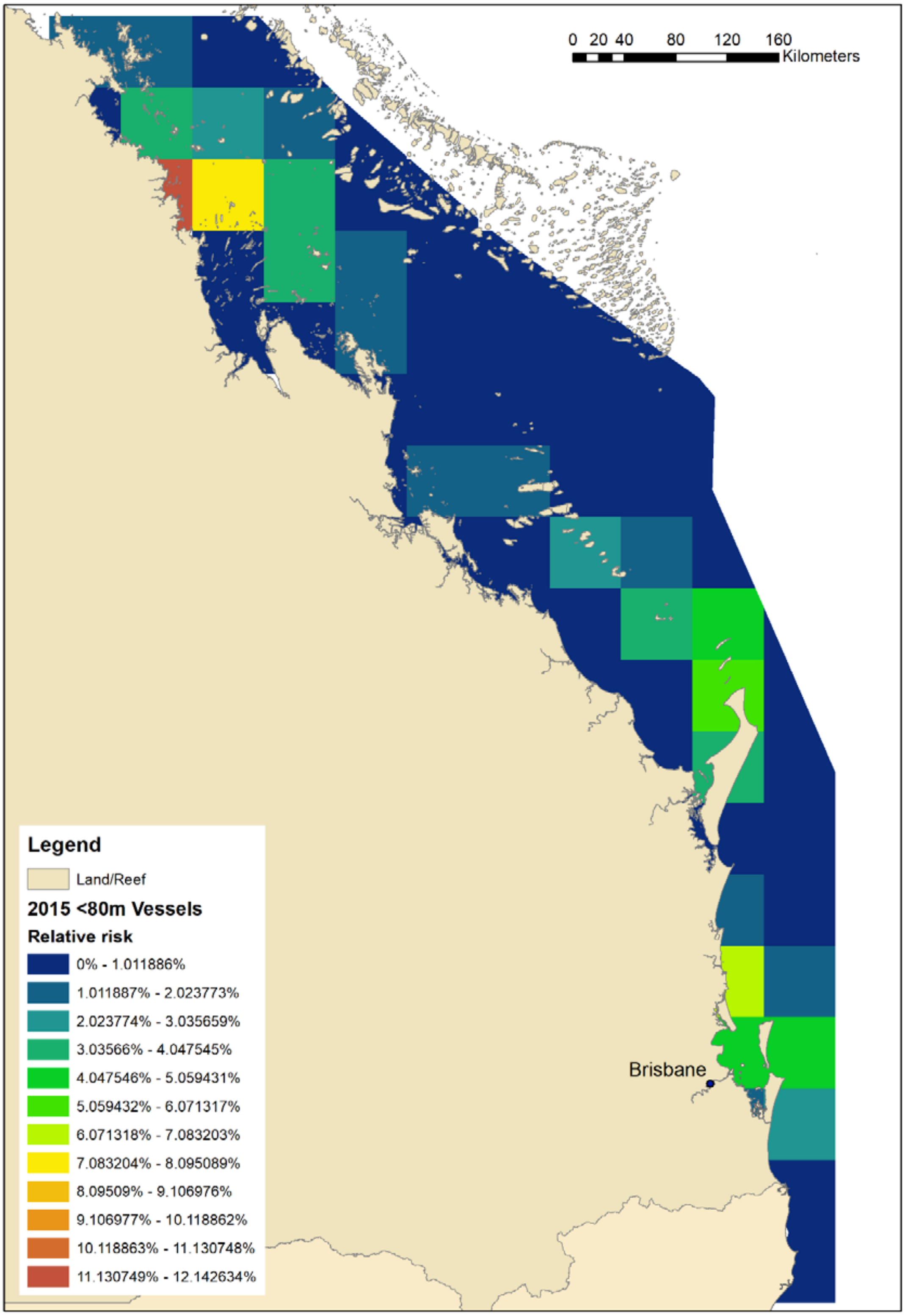


Figure 54 Relative risk of a vessel collision between humpback whales in SEQ and small (<80m in length) AIS equipped vessels

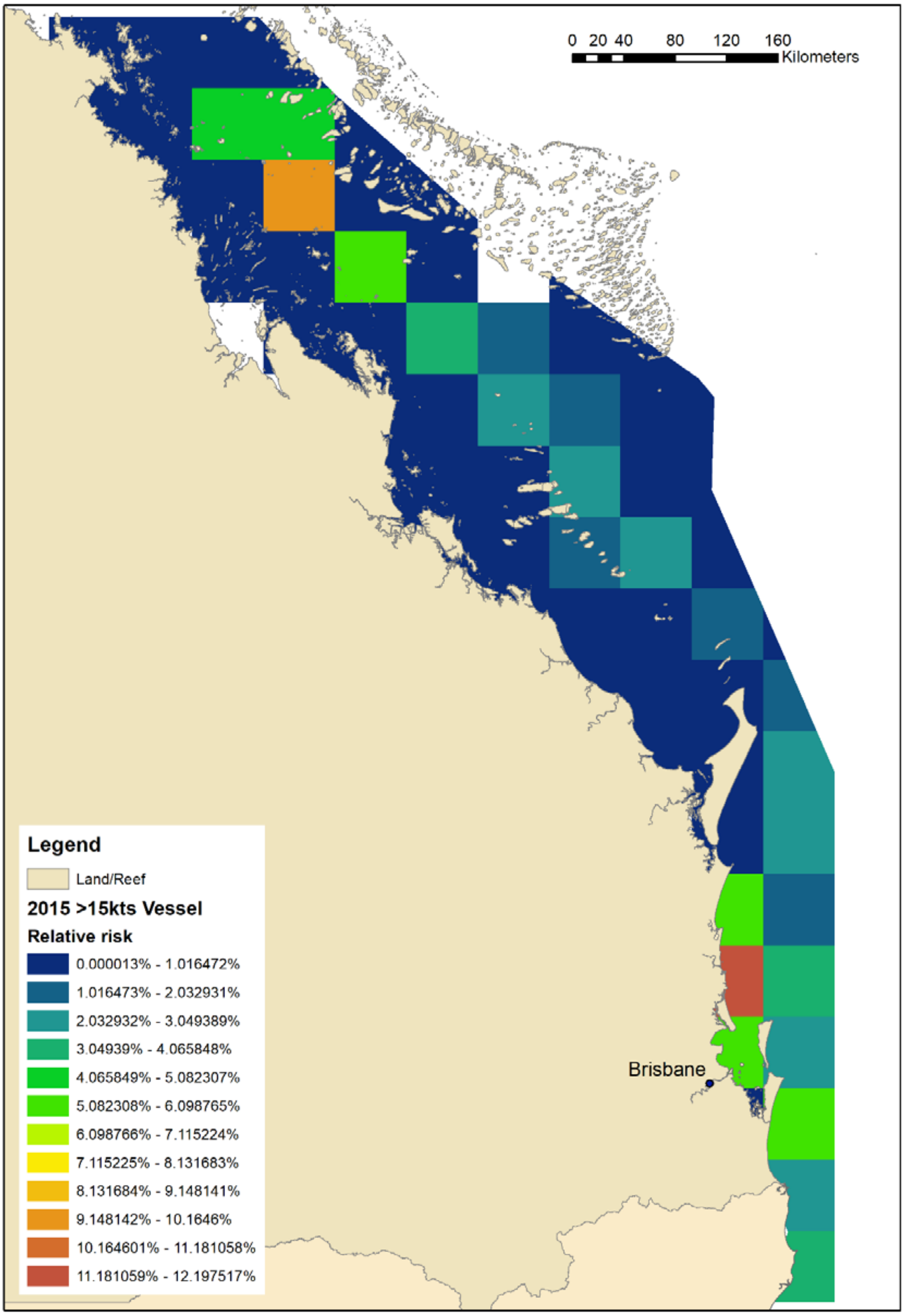


Figure 55 Relative risk of a vessel collision between humpback whales in SEQ and for fast moving (>15kts) AIS equipped vessels

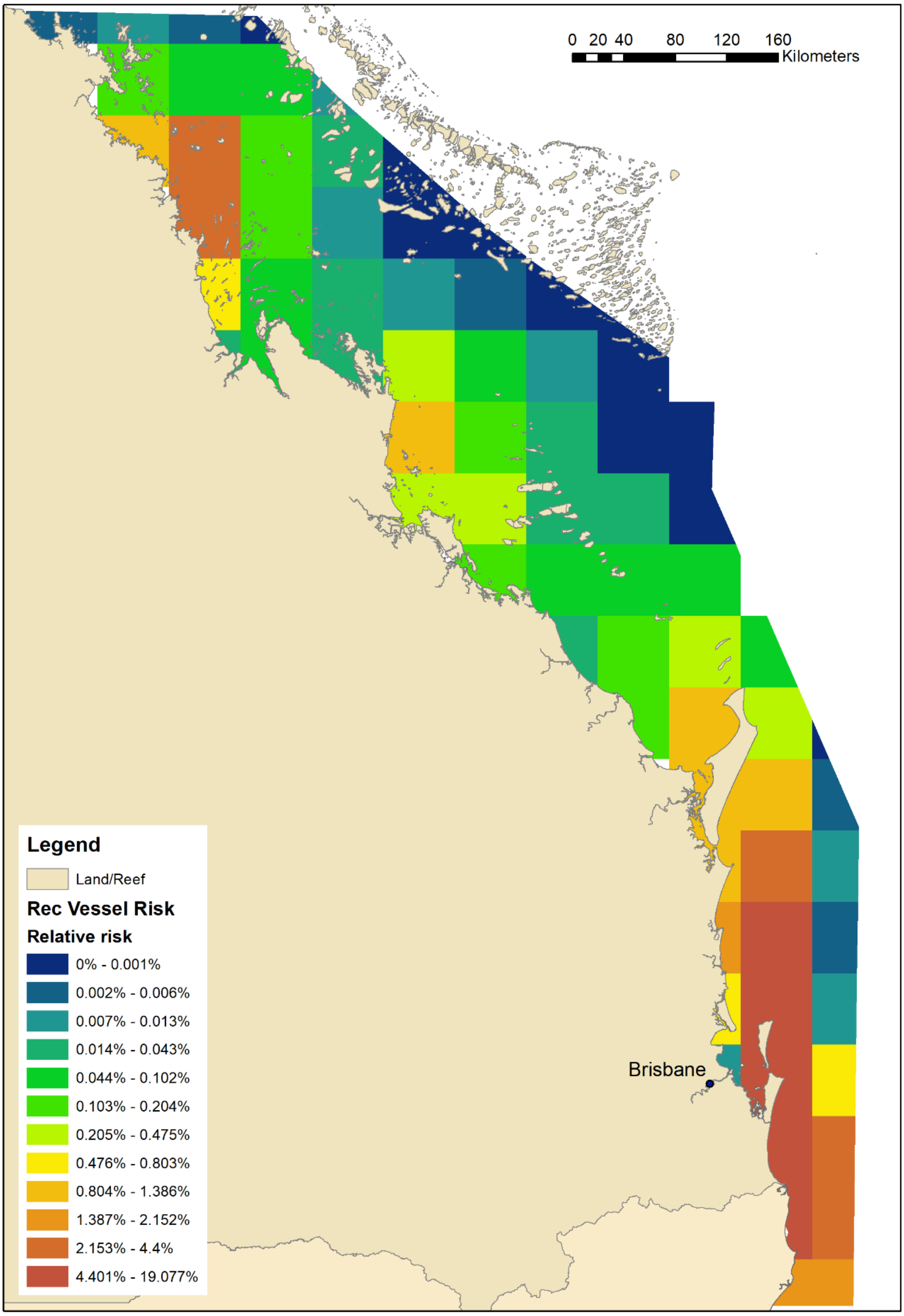


Figure 56 Relative risk of co-occurrence between humpback whales in SEQ and recreational vessels

7.2.4 Risk maps - New South Wales/Biologically Important Areas

The BIA animal range was used in conjunction with the AIS data density and recreational boat model to produce various risk maps (see Table 13). We can compare total risk in the identified usage areas in the BIA (Figure 60 and Figure 61)

Table 13 Summary of data sources and mapping for full Australian East coast Humpback whales based on BIA

Whale Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps	Figures
Polygons of general range (Section 4.3) Source: BIA see Section 7.2.1	Vessels ≥80m Length	2013-2015 AIS Data (See Section 5.1)	Per season (Aug-Sep) 2013-2015 (only 2015 shown in this report)	1/30° 1/2°	Relative risk of a fatal collision (See Section 3.2.1)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 57
	Vessels >15kts speed				Relative risk of a collision[15] (See Section 3.2.2)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 58
	Recreational Vessels	See Section 5.2	Single hypothetical season	1/10 °	Relative co-occurrence	Core area (at 1/2°) and Higher risk areas (at 1/10°)[16]	Figure 59

[15] For vessels less than 80m we are less sure if the probability of fatality curves are relevant so we only calculated risk of collision.
[16] As the recreational vessel model has much greater uncertainty we examine at larger grid size than the AIS data.

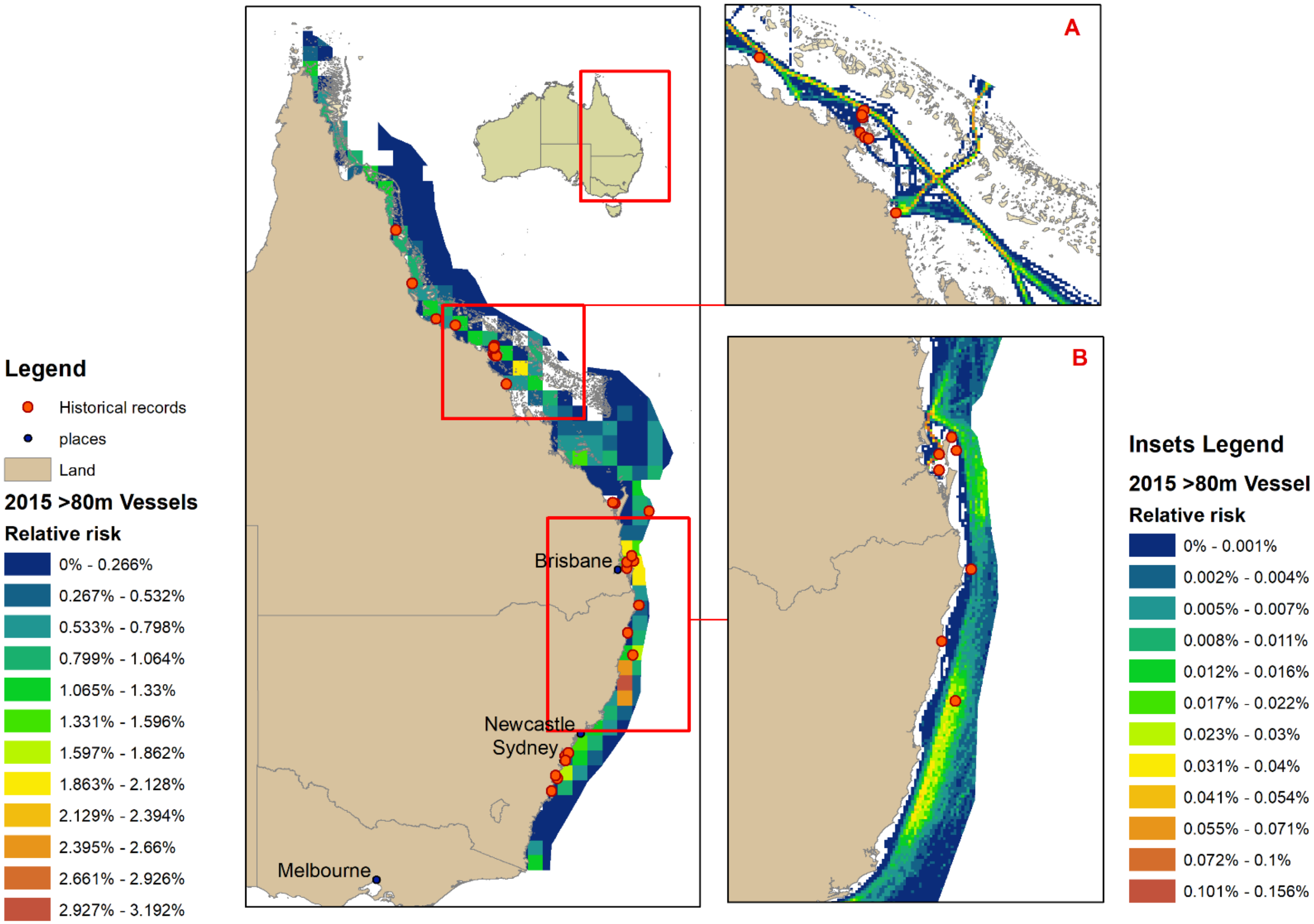


Figure 57 Relative risk of a fatal collision between humpback whales in the East coast Biological Important Area (BIA) and large vessels (>80m in length). Assuming uniform whale distribution across BIA area (BIA from Department of the Environment and Energy 2015), with historical vessel strike locations shown (red circles).

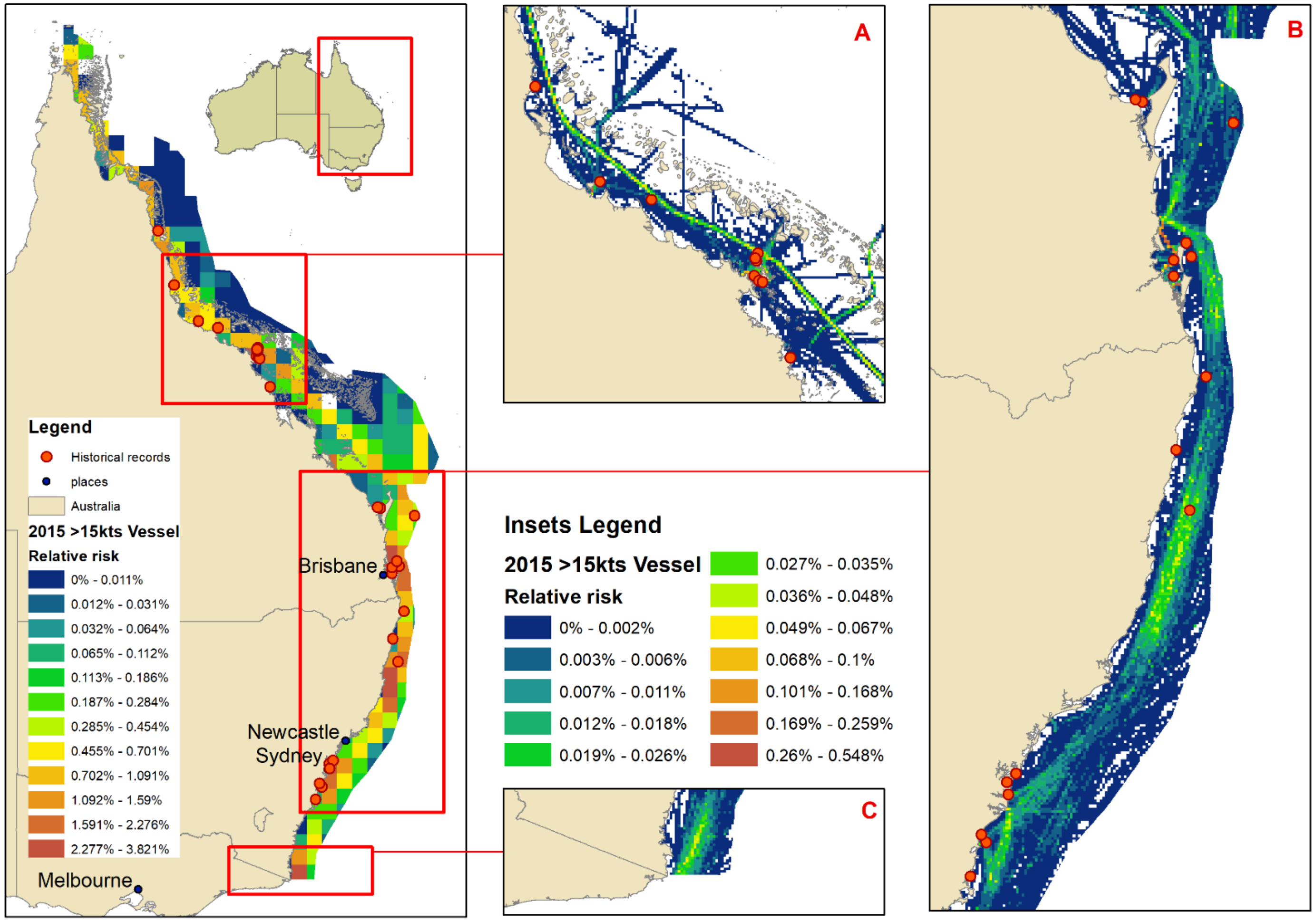


Figure 58 Relative risk of a vessel collision between humpback whales in the East coast Biological Important Area (BIA) and fast moving (>15 knots) vessels. Assuming uniform whale distribution across BIA area (BIA from Department of the Environment and Energy 2015), with historical vessel strike locations shown (red circles).

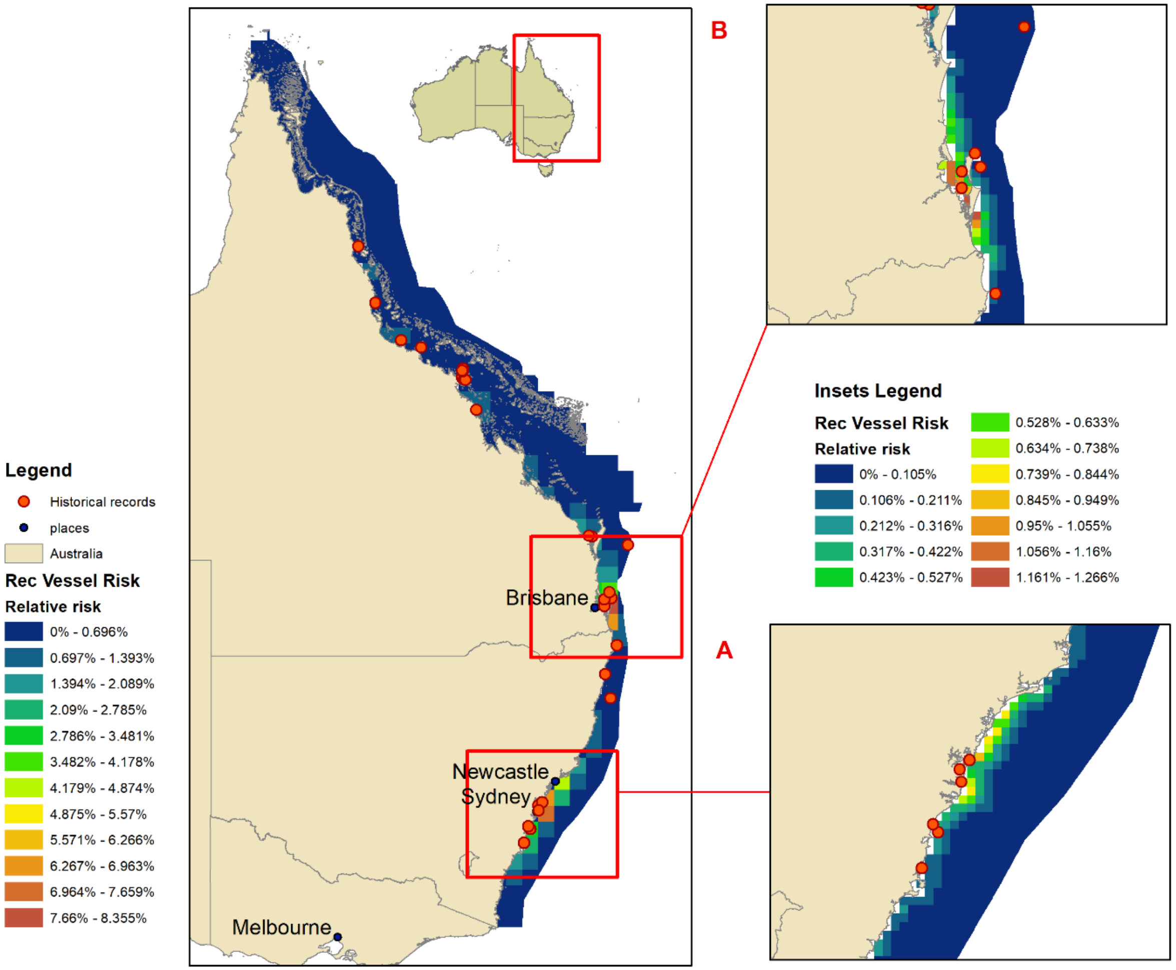


Figure 59 Relative risk of co-occurrence between humpback whales in the East coast Biological Important Area (BIA) and small vessels (<80m in length). Assuming uniform whale distribution across BIA area (BIA from Department of the Environment and Energy 2015), with historical vessel strike locations shown (red circles).

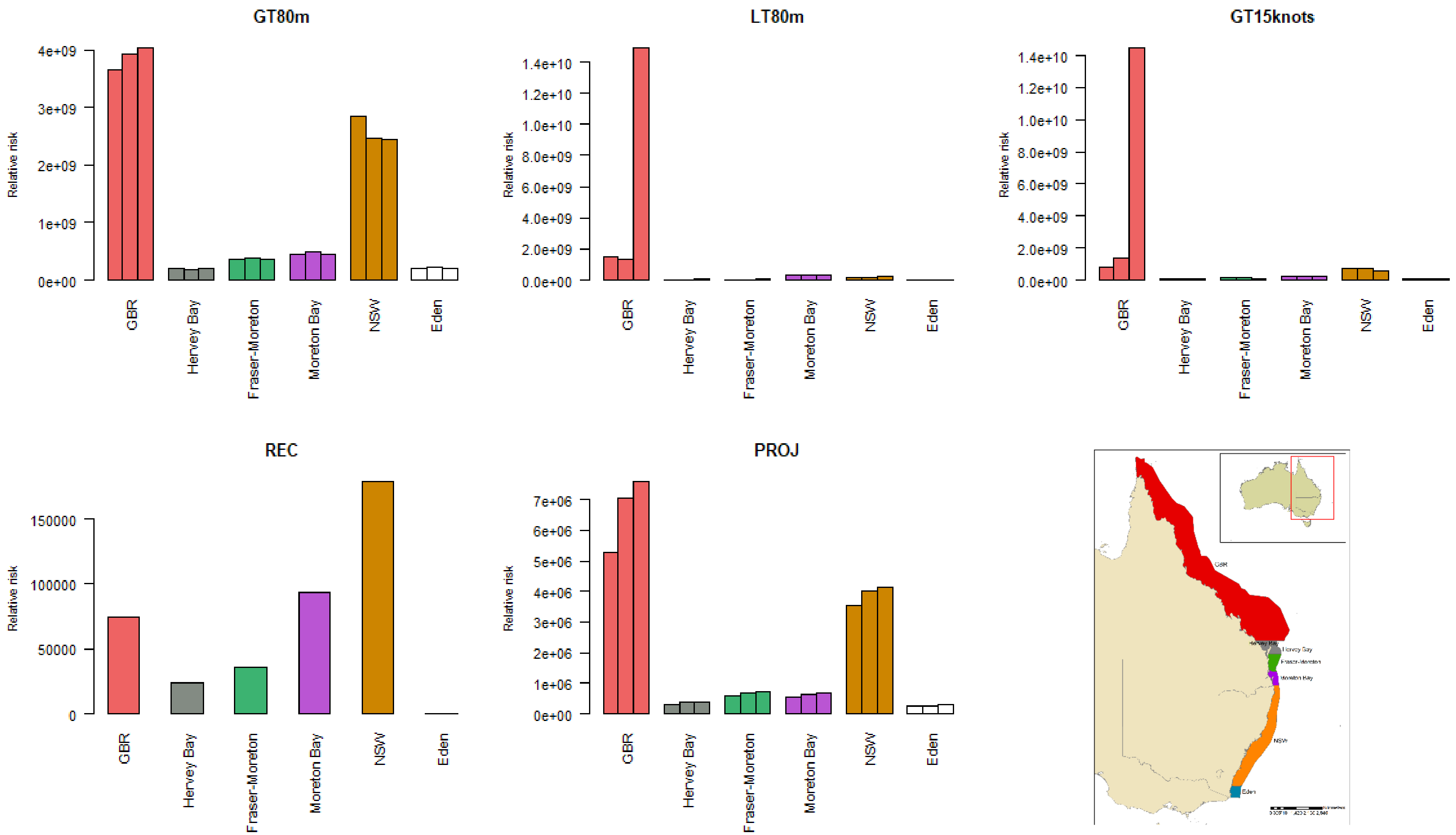


Figure 60 Total Relative risk (using relevant risk metrics as per Table 13) for various vessel data sources for the Biological important areas along the East coast of Australia (each bar is a year left to right 2013, 2014, and 2015)

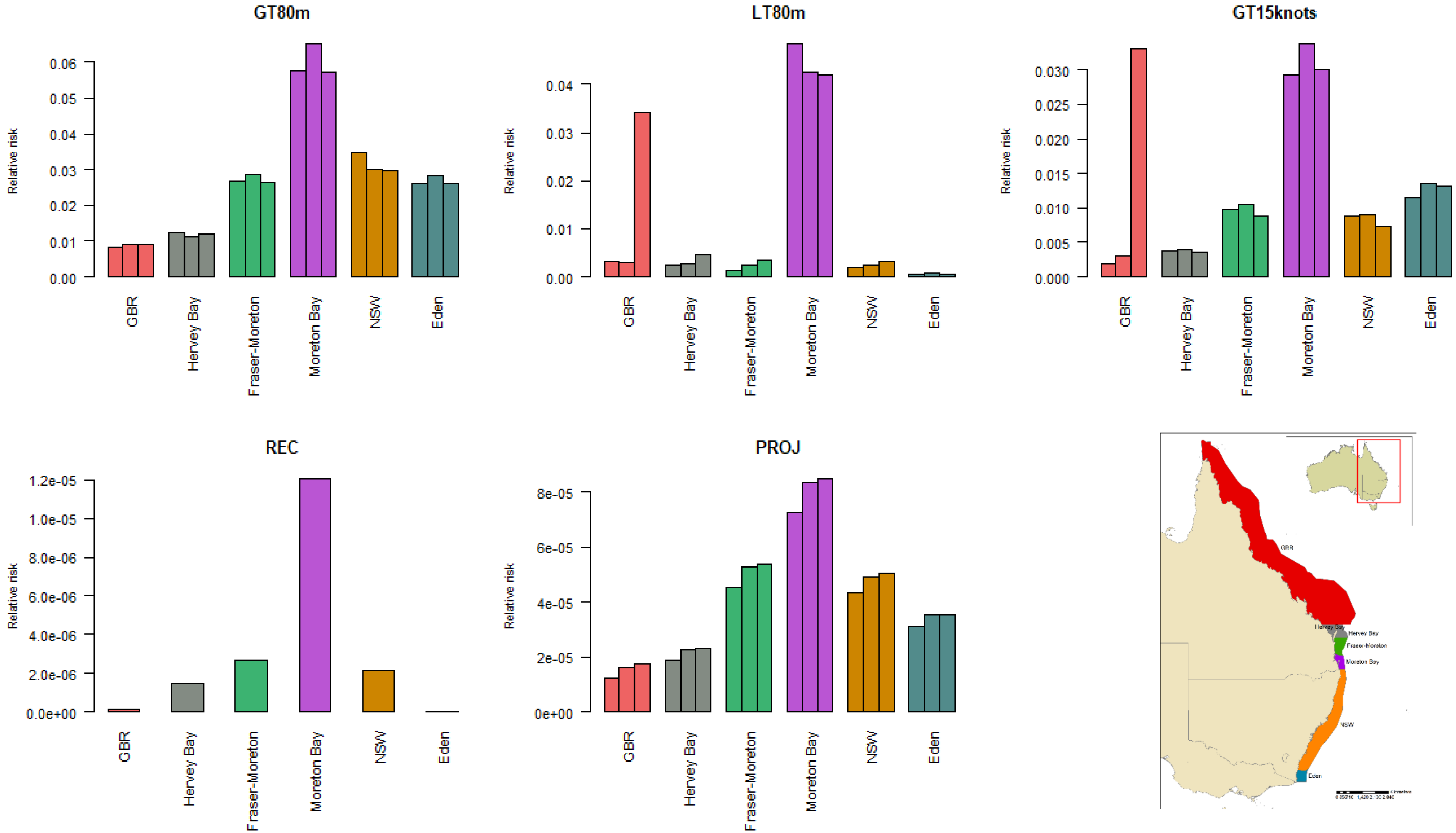


Figure 61 Total Relative risk (using relevant risk metrics as per Table 13) for various vessel data sources for the Biological important areas along the East coast of Australia standardised by BIA area (each bar is a year left to right 2013, 2014, and 2015)

7.2.5 Assumptions and caveats

Assumptions 11 Assumptions and caveats for risk analysis of Eastern Australian humpback whales

General assumptions:

- AIS assumptions and caveats as per Section 5.1.4. The main repercussions of these assumptions for the risk maps are:
    - o The smaller vessels are less represented in the AIS data. Therefore, the <80m vessel risk maps will not be representative of the risk from all vessels <80m and will be under-estimating risk.
- Risk Metric assumption as per Section 3.2.3

For each area, the following assumptions were made:

GBR

- Spatial model assumption as per Assumptions 5 in Section 4.4.
- There is a gap in the spatial model coverage around the Capricorn/Bunker Group in the Southern GBR region where surveys have not yet been completed
- For calculations that take into account whale population increases, the annual rate is assumed to be 10.5% and the increases spatially uniform.

SEQ

- Tag model assumptions as per Assumptions 6 in Section 4.4. In particular, this means that the risk maps indicate risk for a population behaving as per the tagged subset of the population. Specifically, if there are sub-groups within the population that were not captured by the tagging sample regime these animals will be under-represented in the risk. For example, if no animals that utilise a certain resting area were sampled, this resting area will not be represented in the risk map.

New South Wales/Biologically Important Areas

- The aggregation and range areas should not be considered to be complete and are indicative only.

A complete list of caveats and restrictions related to these data is available at the link below[17].

[17] Available at: http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B2ed86f5a-4598-4ae9-924f-ac821c701003%7D

7.2.6 Discussion/Summary

Conclusion G Conclusions for Eastern Australian Humpback Whales

Based on the updated analysis for the GBR, the area **South-East of Mackay** identified in in the AMMC project (Peel et al. 2015) still represents the highest relative risk (Figure 46 - Figure 48, Figure 57). Furthermore, analysis still showed calf groups more at risk than adult groups (Figure 52) and with the risk spread further north (Figure 50, Figure 51). This is based solely on differences in spatial distribution of the groups and not on surface availability or avoidance probability, both of which are unknown so have been assumed to be the same across the population.

Larger size (>80m) AIS equipped vessels

It is hard to compare across the different areas due to different types of animal distribution data not being directly comparable, However, general indications are :

- Overall the GBR region is most likely to have the highest relative risk on the East coast (Figure 60, Figure 61) for large vessels
- In the SEQ region, **North of Brisbane**, and **South-east of Mackay** (Figure 53) have the higher risk profile.
- In the whole of coast BIA analysis[18], other areas with indications of higher risk compared to the rest of the coast are the **Brisbane/Moreton area** and the area off **Port Macquarie** (Figure 57)

On average, between 2013 and 2015, the relative risk per whale for calf groups in the GBR region was 22.6% more than the risk to adult groups (Figure 52).

Between 2013 and 2015 in the GBR region we saw no overall increase in overall risk based on vessel traffic changes (Figure 51), however, increasing humpback population numbers will meant risk was estimated to increase 27.3%, assuming uniform spatial increases.

Smaller size (<80m) AIS equipped vessels

For smaller AIS equipped vessels the areas which seem to have higher risk are:

- In the GBR model, **Mackay** and **Cairns** (Figure 47)
- In the SEQ model, **Brisbane** (Mackay was also indicated however this may be an artefact of the boundary issue causing a spurious density hotspot)(Figure 54)
- In the whole coast BIA analysis[18], although we cannot quantify the risk and directly compare, areas of higher relative risk were **Brisbane**, **Gladstone**, and the **Whitsundays**.

On average, between 2013 and 2015, the risk to calf groups in the GBR region was 63.9% more than the risk to adult groups (Figure 52). This is higher than seen for large vessels due to the smaller vessels being in shallower coastal waters where the calf group density was higher (Figure 50).

In the GBR region we saw a steady increase in risk between 2013 and 2015 (Figure 51), once we standardised for the increase in vessel traffic (Figure 52) the risk per vessel km did not consistently increase. Therefore, it appears the increase in risk between 2013 and 2015 is due to increase in traffic volume rather than any vessel spatial pattern changes.

Fast moving (>15kts) AIS equipped vessels

Indications of areas of higher relative risk were:

---

[18] Note this particular analysis does not take into account animal density beyond restricting the analysis to the BIA species migratory corridor.

- In the GBR model, **Cairns**, the main Shipping lanes between **Townsville to Rockhampton**, and the particularly the **Whitsundays** (Figure 48).
- In the SEQ model, **North of Brisbane**, most of **lower southeast Queensland**, and the shipping lanes **South-east of Mackay** (Figure 55).
- In the whole of coast BIA analysis[18], **Whitsundays**, **Brisbane/Moreton Bay Area**, **Port Macquarie**, **Northern Sydney**, and **Eden** (Figure 58).

On average, between 2013 and 2015, the risk to calf groups in the GBR region was 4.2% more than the risk to adult groups.

Between 2013 and 2015 in the GBR region we saw no overall increase in risk based on vessel traffic changes (Figure 51), however, increasing humpback population numbers will mean risk will have increased.

Recreational vessels

As expected, for recreational vessels relative risk was correlated to population centres, e.g., in the GBR model **Cairns** and **Mackay** (Figure 49), SEQ model **Brisbane** (Figure 56) and BIA analysis **around Sydney, and Brisbane** (Figure 59).

Recommendations to improve risk analysis

- Better spatial information for **NSW/TAS** (e.g., animal density or improved definition of migratory corridor/resting areas)
- Fill the gap in the GBR distribution with survey data and spatial model for the **Capricorn/Bunker Group** in the Southern GBR region.
- Gathering more information on parameters such as surface/dive behaviour and behavioural response (immediate vicinity of vessels and broadscale with respect to shipping lanes).

7.3 Southern right whale

7.3.1 Data source

There is currently no complete distribution model for Southern right whales in Australian waters. However, aggregation areas have been identified and a core and overall distribution identified by the Department of Environment and Energy (From Department of Sustainability, Environment, Water, Population and Communities, 2012).

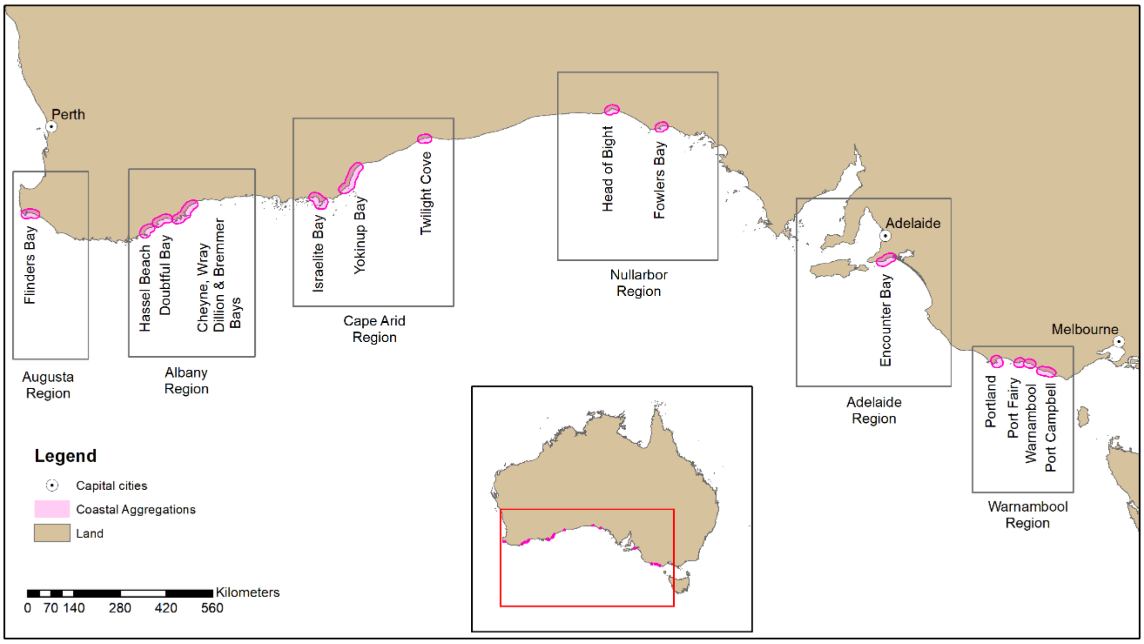


Figure 62 Locations of identified Southern Right whale coastal aggregations (From Department of Sustainability, Environment, Water, Population and Communities, 2012)

Also identified are:

a) Core area - The main area the species are likely to be found
b) General range – A range in which the species may occur
c) Historical areas – Areas which were historically used by the species

7.3.2 Risk maps

The animal range and aggregations were used in conjunction with the AIS data density models and a recreational vessel model to produce various risk maps (see Table 14). We can compare the relative risk across the aggregations (Figure 70) and look at any changes in projected future risk (Figure 71).

Table 14 Summary of data sources used and main mapping for Southern Right whale risk analysis

Whale Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps	Figures
Polygons of: a) Core area b) General Range c) Aggregations d) Historical areas (See Section 4.3) Source: From recovery plan (see Section 7.3.1)	Vessels ≥80m Length	2013-2015 AIS Data (See Section 5.1)	Per season (May-Nov) 2013-2015 (only 2015 shown in this report)	1/30° 1/2°	Relative risk of a fatal collision (See Section 3.2.1)	Core area (at 1/2°)	Figure 63
						Aggregation areas (at 1/30°)	Figure 64 Figure 70
	Vessels <80m Length				Relative risk of a collision[1] (See Section 3.2.2)	Aggregation areas (at 1/30°)	Figure 66
	Vessels >15kts speed				Relative risk of a collision[1] (See Section 3.2.2)	Core area (at 1/2°)	Figure 67
						Aggregation areas (at 1/30°)	Figure 68
	Recreational Vessels	See Section 5.2	Single hypothetical season	1/10 °	Relative co-occurrence (See Section 3.2.3)	Aggregation areas (at 1/10°)[2]	Figure 69

[1] For smaller vessels we are less sure if the probability of fatality curves are relevant so we only calculated risk of collision.
[2] As the recreational vessel model has much greater uncertainty we examine at larger grid size than the AIS data.

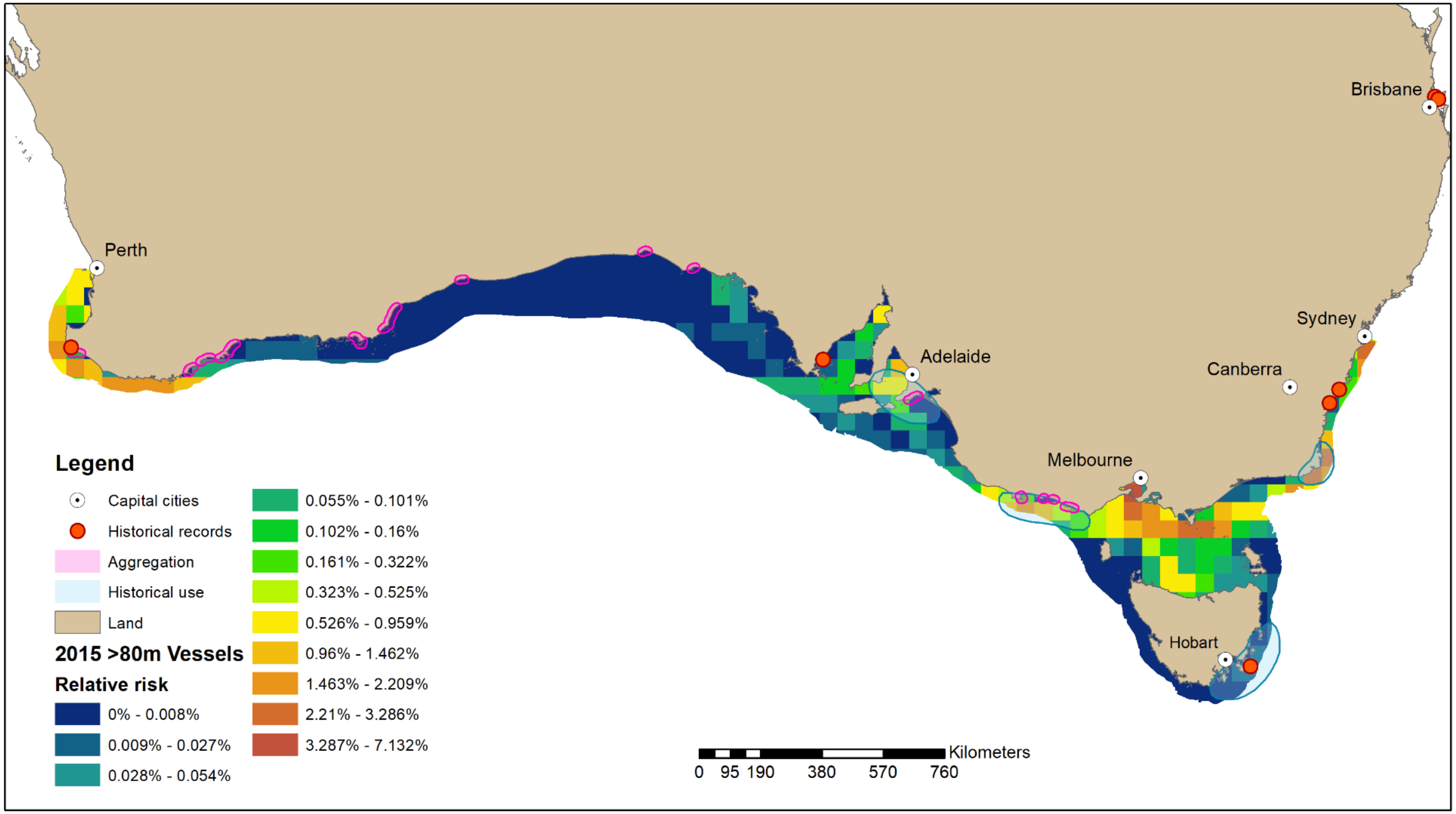


Figure 63 Relative risk of a fatal collision in the Southern Right whales core area (assuming uniform animal density) with large (length >80m) AIS equipped vessels in 2015 (core areas based on data from Department of Sustainability, Environment, Water, Population and Communities, 2012)

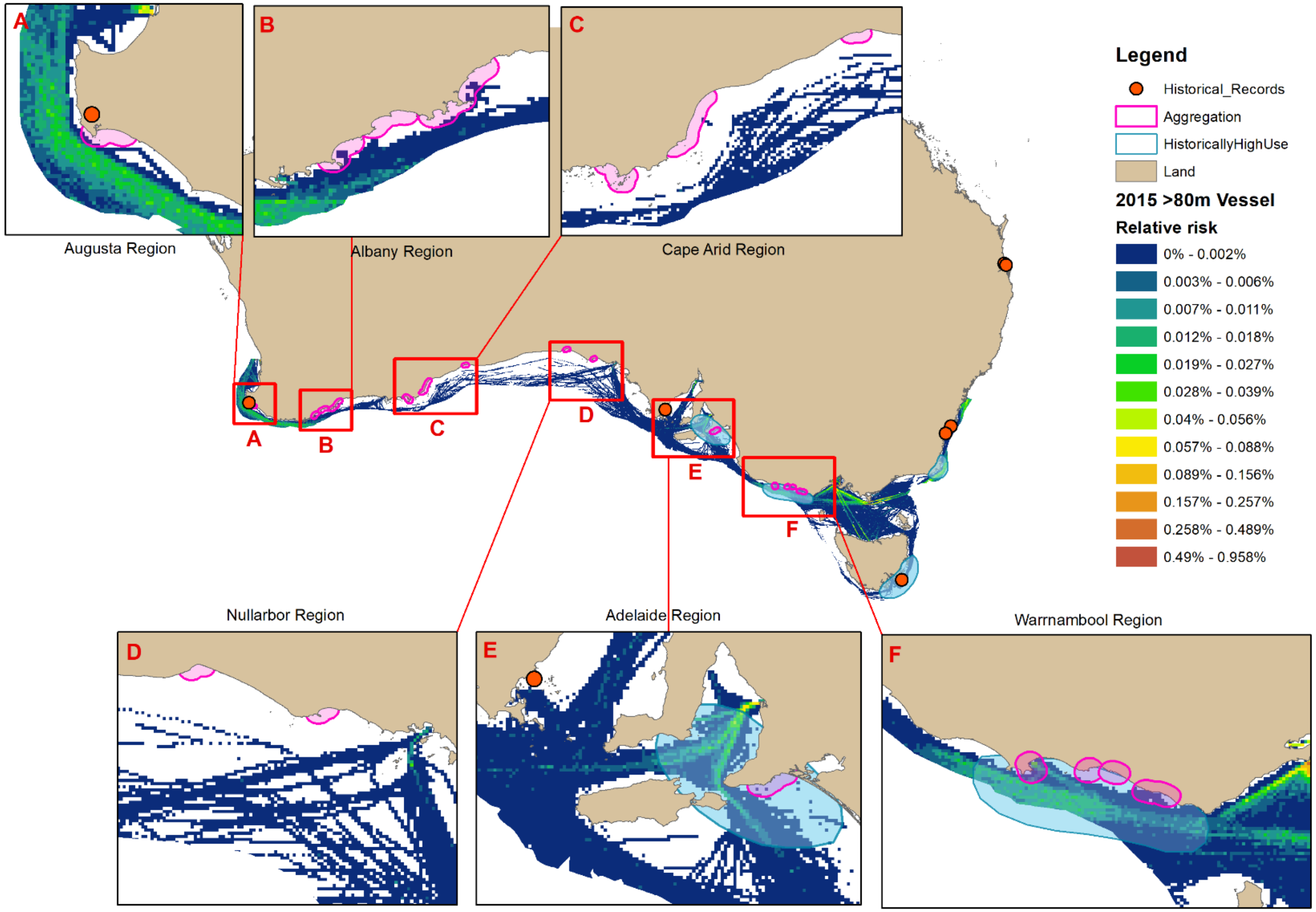


Figure 64 Relative risk of a fatal collision within Southern Right whale aggregation areas (assuming uniform animal density within and across aggregations) with large (>80m in length) AIS equipped vessels, in 2015 (aggregation areas from Department of Sustainability, Environment, Water, Population and Communities, 2012)

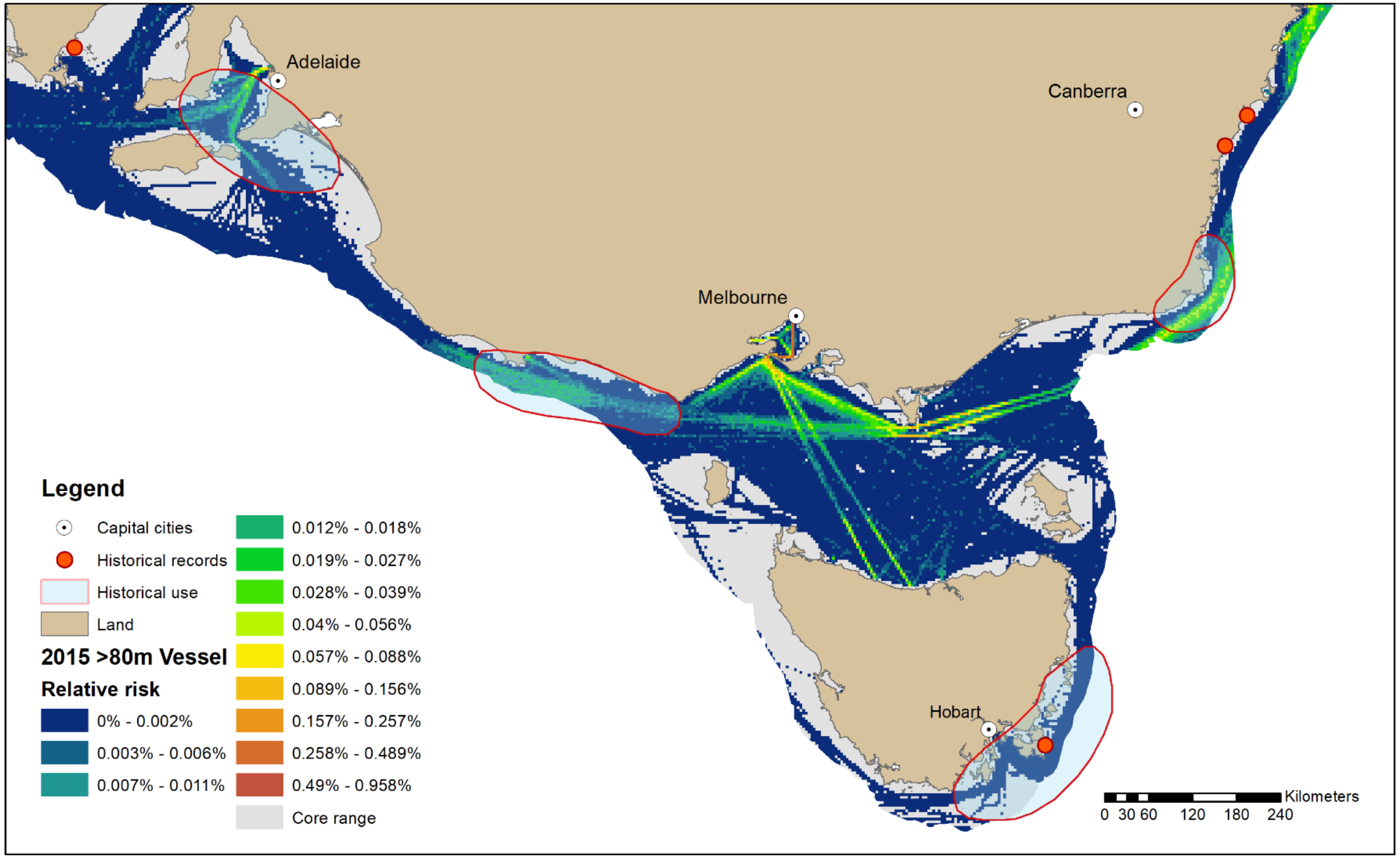


Figure 65 Relative risk of a fatal collision in areas of Southern Right whale historical use (assuming uniform animal density within and across historical areas) for large (>80m of length) AIS equipped vessels, in 2015 (Historical areas from Department of Sustainability, Environment, Water, Population and Communities, 2012)

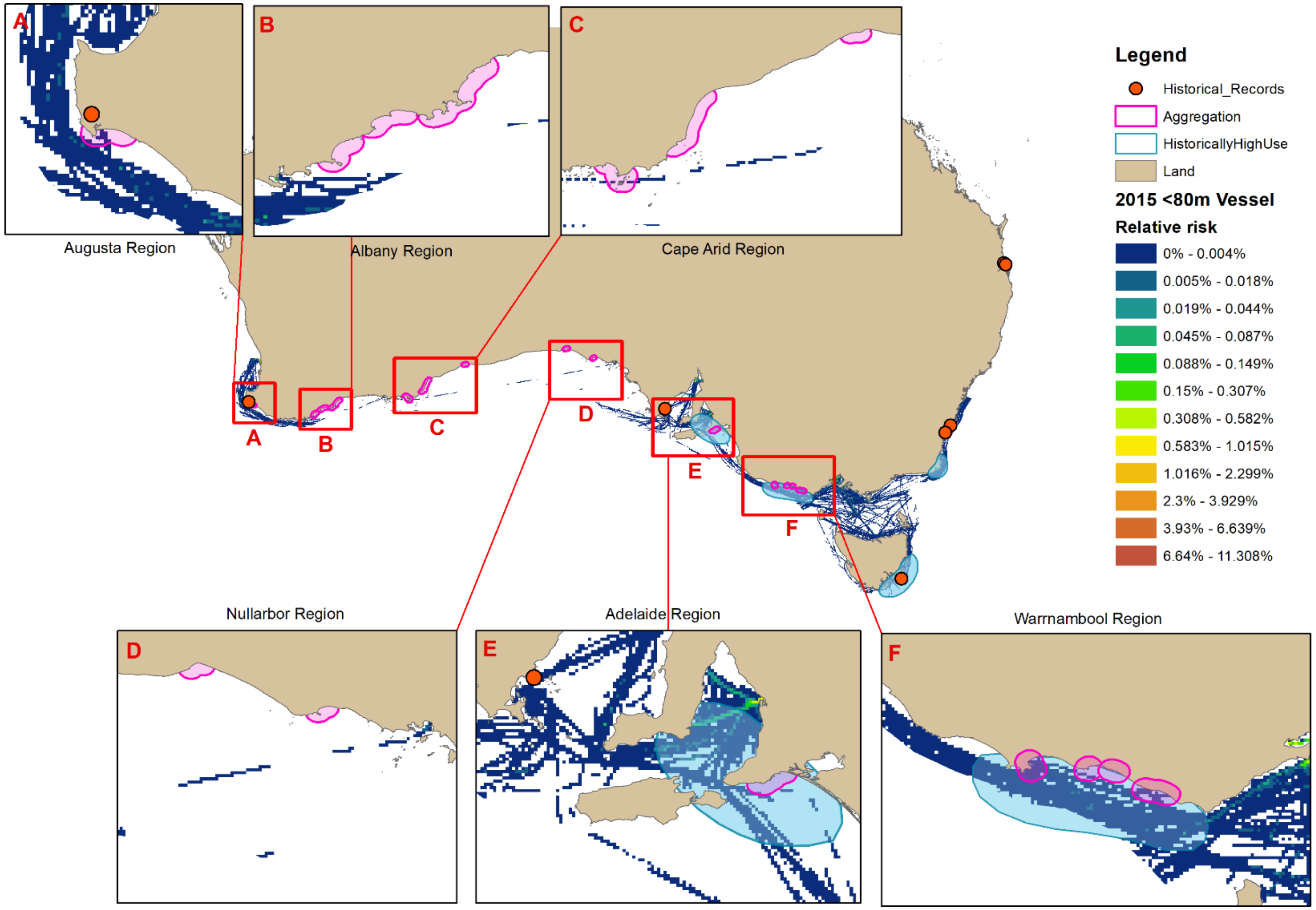


Figure 66 Relative risk of a collision within Southern Right whale aggregation areas (assuming uniform animal density within and across aggregations) with small (<80m in length) AIS equipped vessels, in 2015 (aggregation areas from Department of Sustainability, Environment, Water, Population and Communities, 2012)

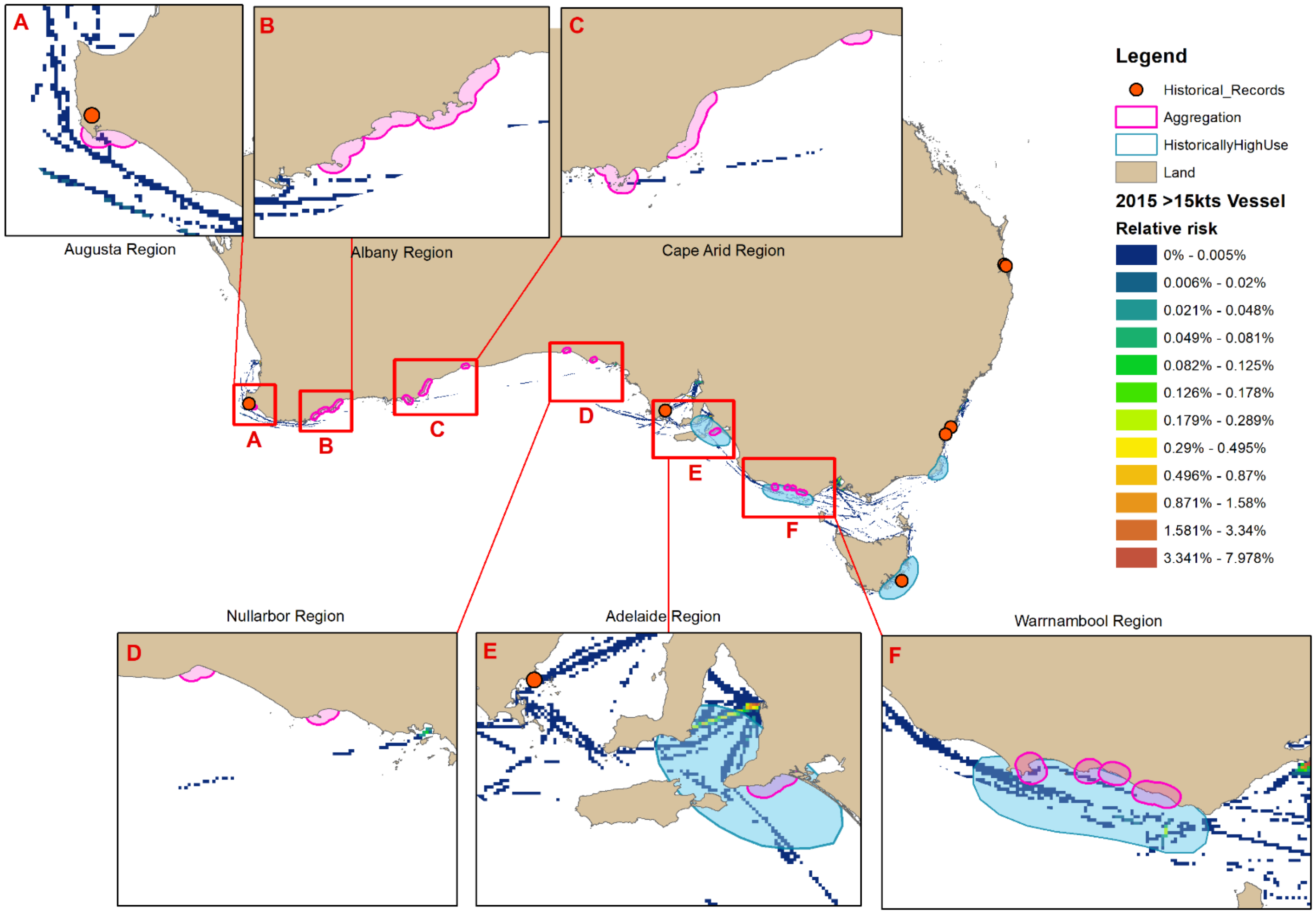


Figure 67 Relative risk of a collision within Southern Right whale aggregation areas (assuming uniform animal density within and across aggregations) with fast moving (>15 knots) AIS equipped vessels, in 2015 (aggregation areas from Department of Sustainability, Environment, Water, Population and Communities, 2012)

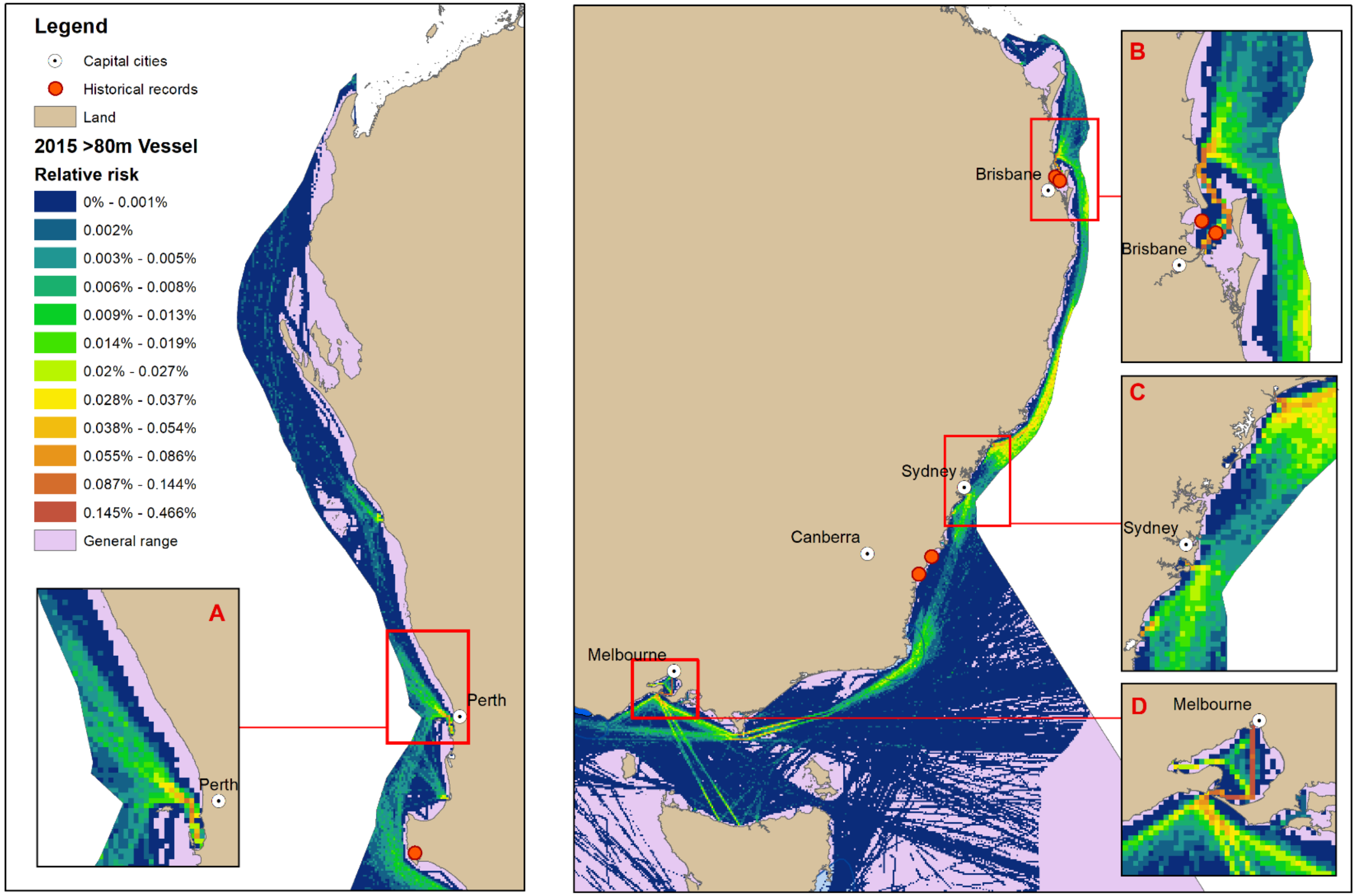


Figure 68 Relative risk of a fatal collision within the general Southern right whale range (assuming uniform animal density with large (>80m) AIS equipped vessels, (general range from Department of Sustainability, Environment, Water, Population and Communities, 2012)

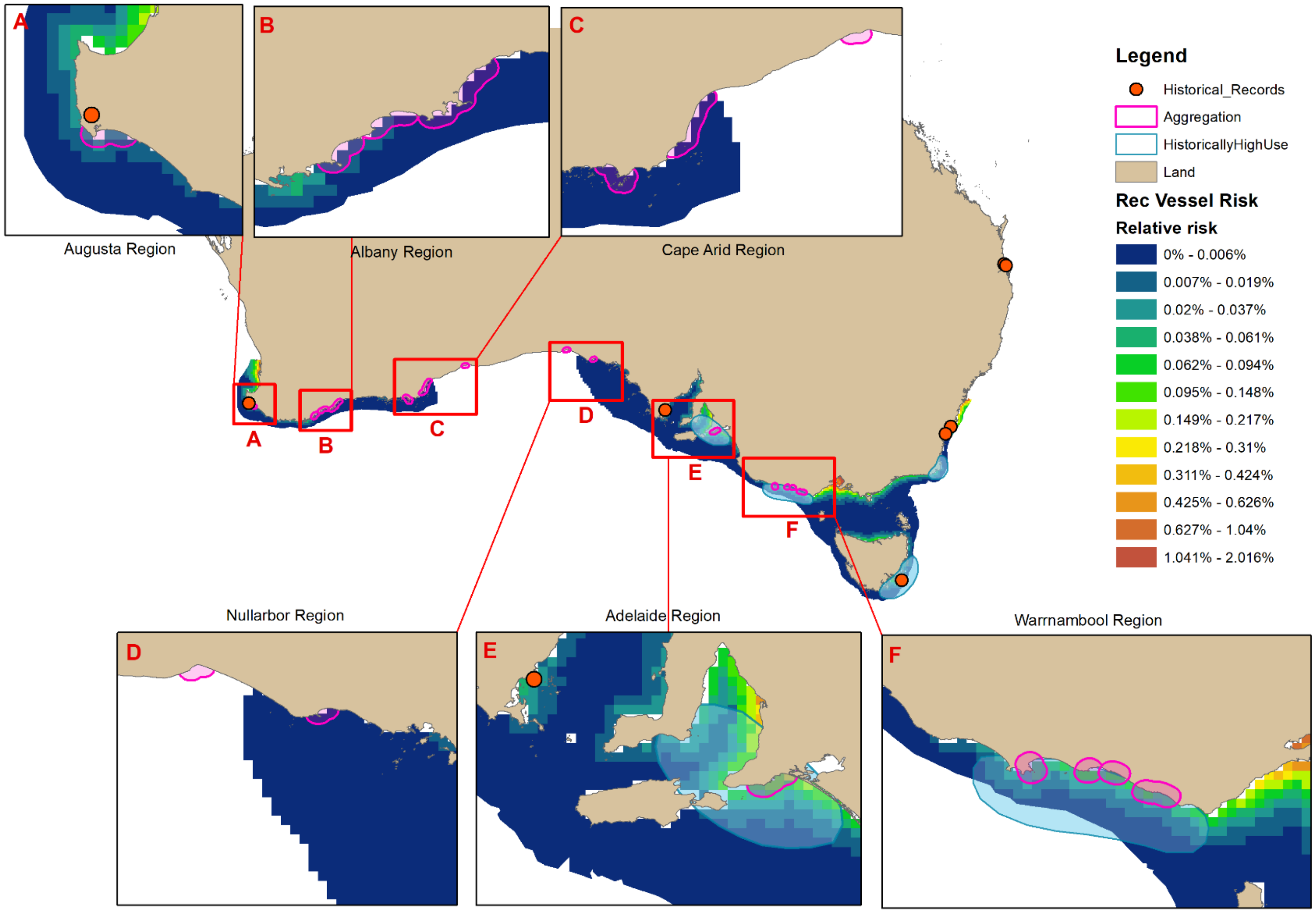


Figure 69 Relative risk of a co-occurrence within Southern Right whale aggregation areas (assuming uniform animal density within and across aggregations) with recreational vessels (aggregation areas from Department of Sustainability, Environment, Water, Population and Communities, 2012)

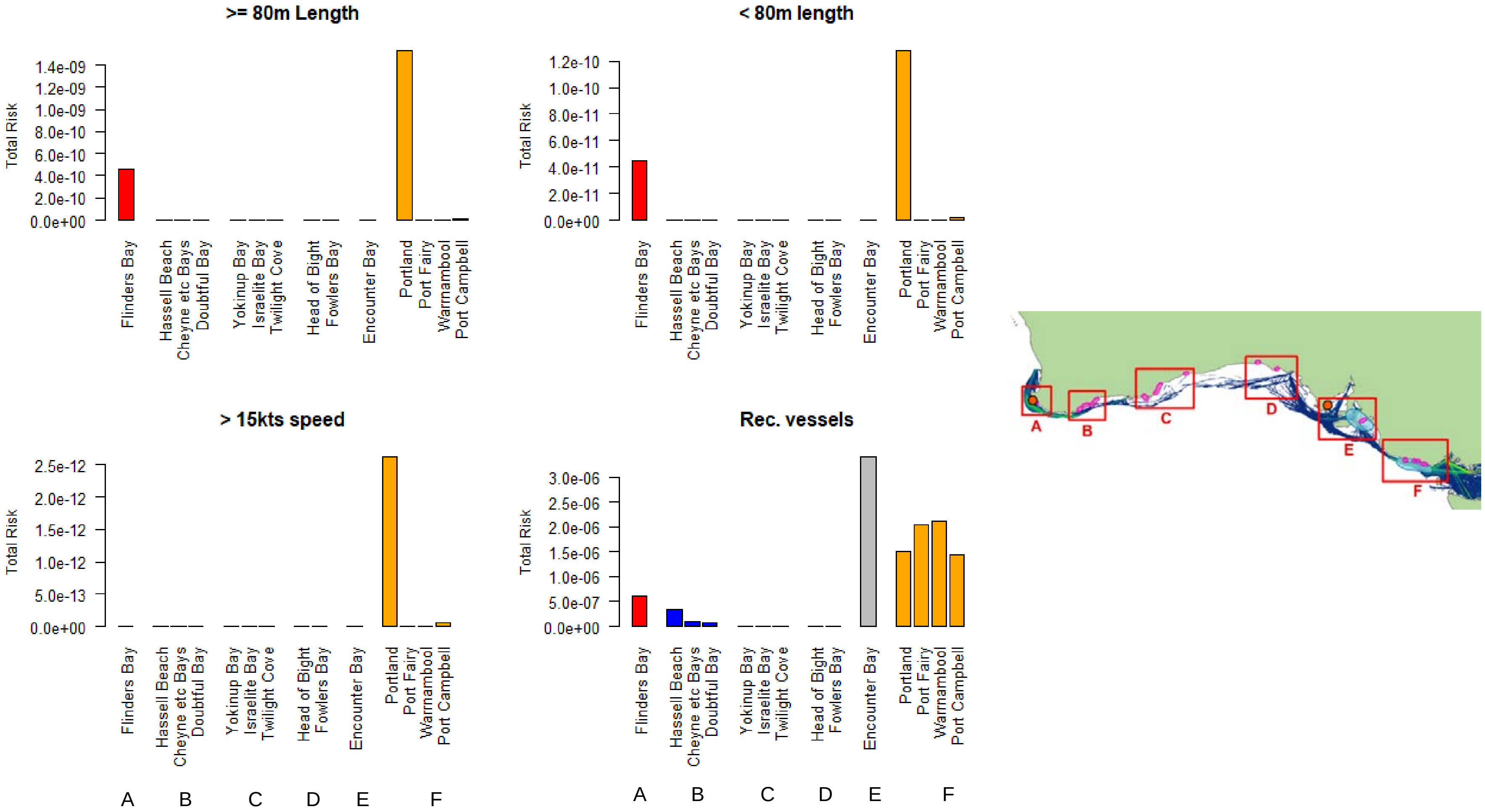


Figure 70 Total relative risk (using relevant risk metric from Table 14) standardised by aggregation area m^2 for each Southern right whale aggregation area for various vessel data sources in 2015 (aggregation areas from Dep. Environment, Water, Population and Communities, 2012)

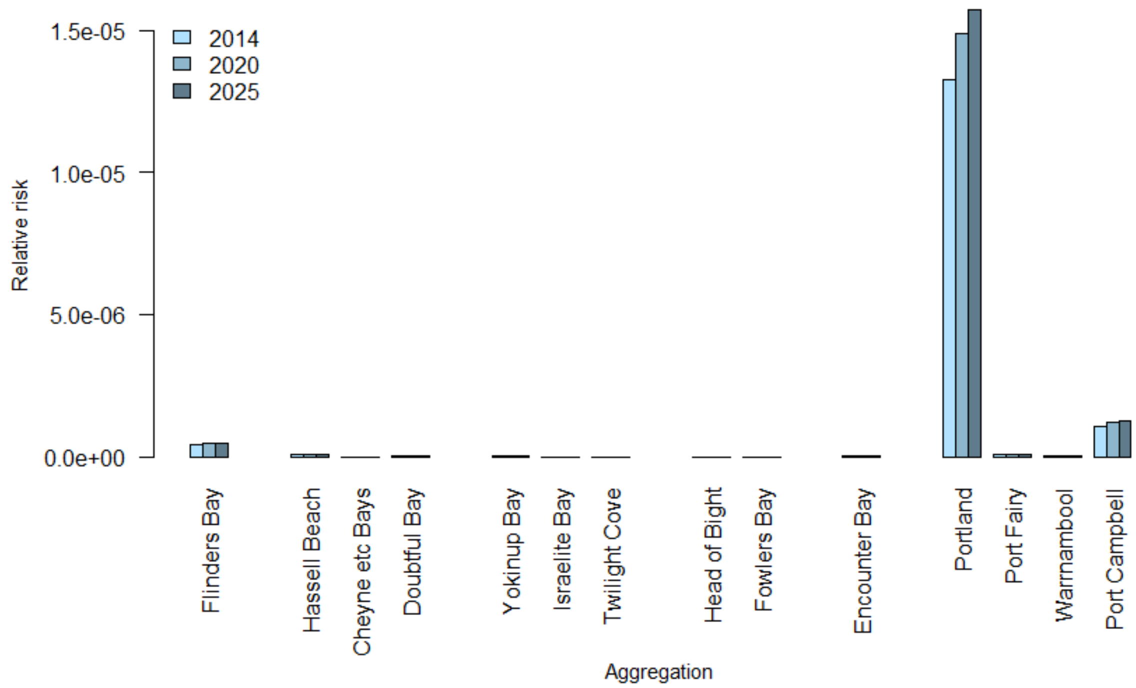


Figure 71 Total relative risk of co-occurrence in Southern Right whale aggregations for projected future AIS traffic, standardised by aggregation area m^2 (aggregation areas from Dep. Environment, Water, Population and Communities, 2012)

7.3.3 Assumptions and caveats

Assumptions 12 Assumptions and caveats for risk analysis of Southern Right whales

The following assumptions were made:

- AIS assumptions and caveats as per Section 5.1.4. The main repercussions for the risk maps are:
    - o The smaller vessels are less represented in the AIS data. Therefore, the <80m vessel risk maps will not be representative of the risk from all vessels <80m and will be under-estimates of overall risk.
- Risk Metric assumption as per Section 3.2.3
- The aggregation and range areas provided by DoEE and were developed in 2011 for the specific purpose of informing the Recovery Plan. As such, these should not be considered to be complete and are indicative only.
- No animal density is known when core range polygons were used so we have to assume uniform density which is likely to be highly unrealistic. Another way of thinking of this risk metric, is that this is the relative spatial risk of a single whale that could be anywhere in the animal's core range.

7.3.4 Discussion/Summary

Conclusion H Conclusions for Southern Right Whales

Due to not having animal density or abundance of coastal aggregations, the results cannot take into account differing spatial densities of the animals. However, there was some general indications of where relative risk is potentially higher.

Larger size (>80m) AIS equipped vessels

The areas of highest relative risk of fatalities for large vessels (>80m length) are the **Southern Western Australian coast** and **Bass Strait off the Victorian coast** and to a lesser extent off the **NSW coast up to Sydney** (Figure 63).

We know that animal distribution will not be uniform and there are some known coastal aggregation areas (Figure 64). We can focus on these areas and look at vessel risk (Figure 64) assuming density within the aggregation is uniform. Many of the aggregations do not interact with major shipping routes (Figure 64). Of the aggregations, the **Portland** aggregation at the far left of the **Warrnambool** map (Figure 64F) is the main aggregation with encroachment of large vessels. The amount of overlap can be quantified if we assume the same whale density at each aggregation and looking at the total relative risk within each aggregation (standardised for the area covered by the aggregation). The **Portland region** has highest risk per m^2 relative to the other aggregations (Figure 70A).

So far, we have only been considering shipping inside the defined aggregation areas. However, it should be noted that animals must travel to and from these aggregations and all of the aggregations are to some extent surrounded by vessel routes. In particular the **Augusta** (Figure 64A), **Albany** (Figure 64B) and **Warrnambool** (Figure 64F) regions are adjacent to well used vessel routes.

Looking at the areas of historical use **Adelaide, Warrnambool, and NSW region** all have high density of vessel traffic passing through them and the Hobart area less (Figure 65).

Smaller size (<80m) AIS equipped vessels

Similarly, we can look at the smaller AIS equipped vessels (<80m length) around the coastal aggregation areas (Figure 66).

Fast moving (>15kts) AIS equipped vessels

For fast vessels, there was little activity in or near the coastal aggregations (Figure 67). However, it is difficult to quantify the difference in risk of vessel strike as faster moving vessels may be likely to have collisions and the injury/fatality risk will be higher. Looking at the broader animal distribution the areas with the highest density of fast moving vessels within the animal's range are the **Brisbane/Moreton Bay** area and the **Sydney area** (Figure 68).

Recreational vessels

The recreational models are preliminary models that need to be further developed. However, on a broad scale and as expected the coastal aggregations near the higher human populated areas of **Adelaide and Melbourne** show increased risk compared to the more remote aggregation areas (Figure 69).

Recommendations to improve risk analysis

- Better overall distributional data
- Data on the spatial consistency of the aggregation areas year to year
- Abundance estimation for the coastal aggregations
- Fine-scale movement data in and around coastal aggregation areas

7.4 Sperm whale

7.4.1 Data source

There is currently no complete distribution model for Sperm whales in Australian waters. However, aggregation areas have been identified (i.e., Biological importance Areas (BIA) - Department of Environment and Energy 2015) and an overall distribution (i.e., Species of National Environmental Significance database (SNES) - Department of the Environment 1998) (**Figure 72**).

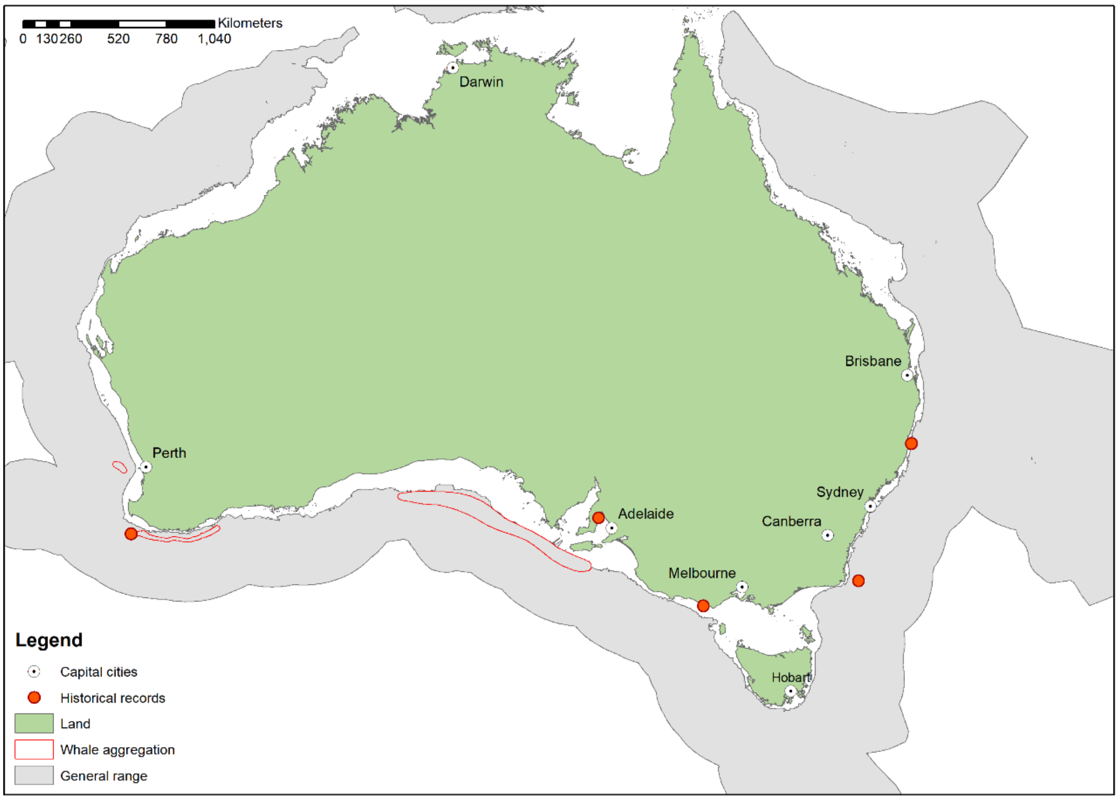


Figure 72 Sperm whale BIA species range and aggregations (DoEE 2015), with historical vessel strike locations denoted (red circles).

7.4.2 Risk maps

The animal range and aggregations were used in conjunction with the AIS data density and recreational boat model to produce various risk maps (see Table 15). We can compare the relative risk across the aggregations (Figure 77) and look at any changes in projected future risk (Figure 78).

Table 15 Summary of data sources used and main mapping for Sperm whale risk analysis

Whale Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps	Figures
Polygons of: b) General Range c) Aggregations (See Section 4.3) Source: BIA from DOEE (2015) and SNES from DOE (1998) (See Section 7.4.1)	Vessels ≥80m Length	2013-2015 AIS Data (See Section 5.1)	All year round 2013-2015 (only 2015 shown in this report)	1/30° 1/2°	Relative risk of a fatal collision (See Section 3.2.1)	Core area (at 1/2°)	Figure 73
						Aggregation areas (at 1/30°)	Figure 74
	Vessels <80m Length				Relative risk of a collision[1] (See Section 3.2.2)	Aggregation areas (at 1/30°)	Figure 75
	Vessels >15kts speed				Relative risk of a collision[1] (See Section 3.2.2)	Core area (at 1/2°)	Figure 76

[1] We have no probability of fatality curves for turtles so we only calculated risk of collision.

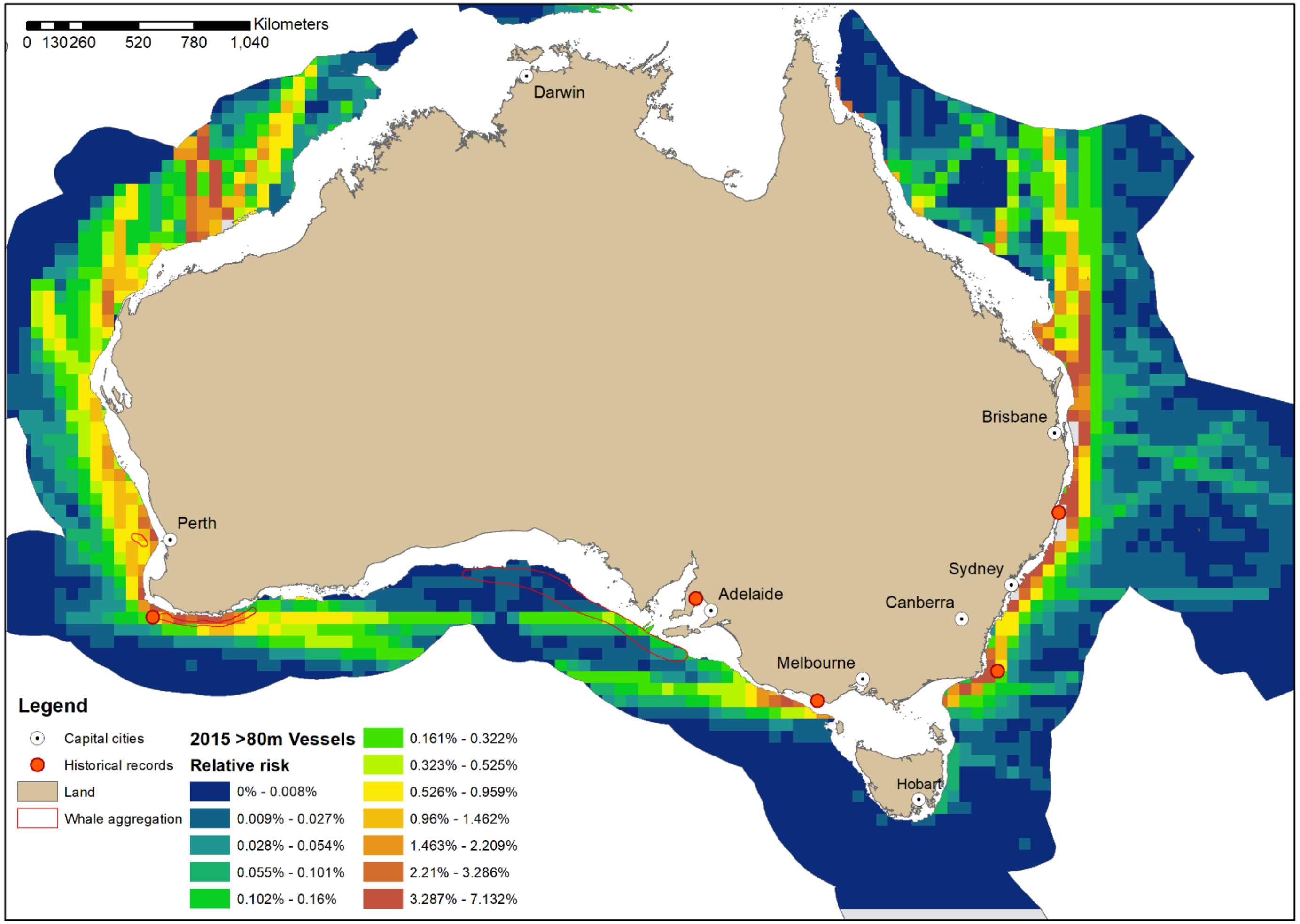


Figure 73 Relative risk of a fatal collision in the general sperm whale species range (assuming uniform density within range) for large (>80m) AIS equipped vessels in 2015 (Range supplied by DoEE 2015 & DOE 1998), with historical vessel strike locations shown (red circles)

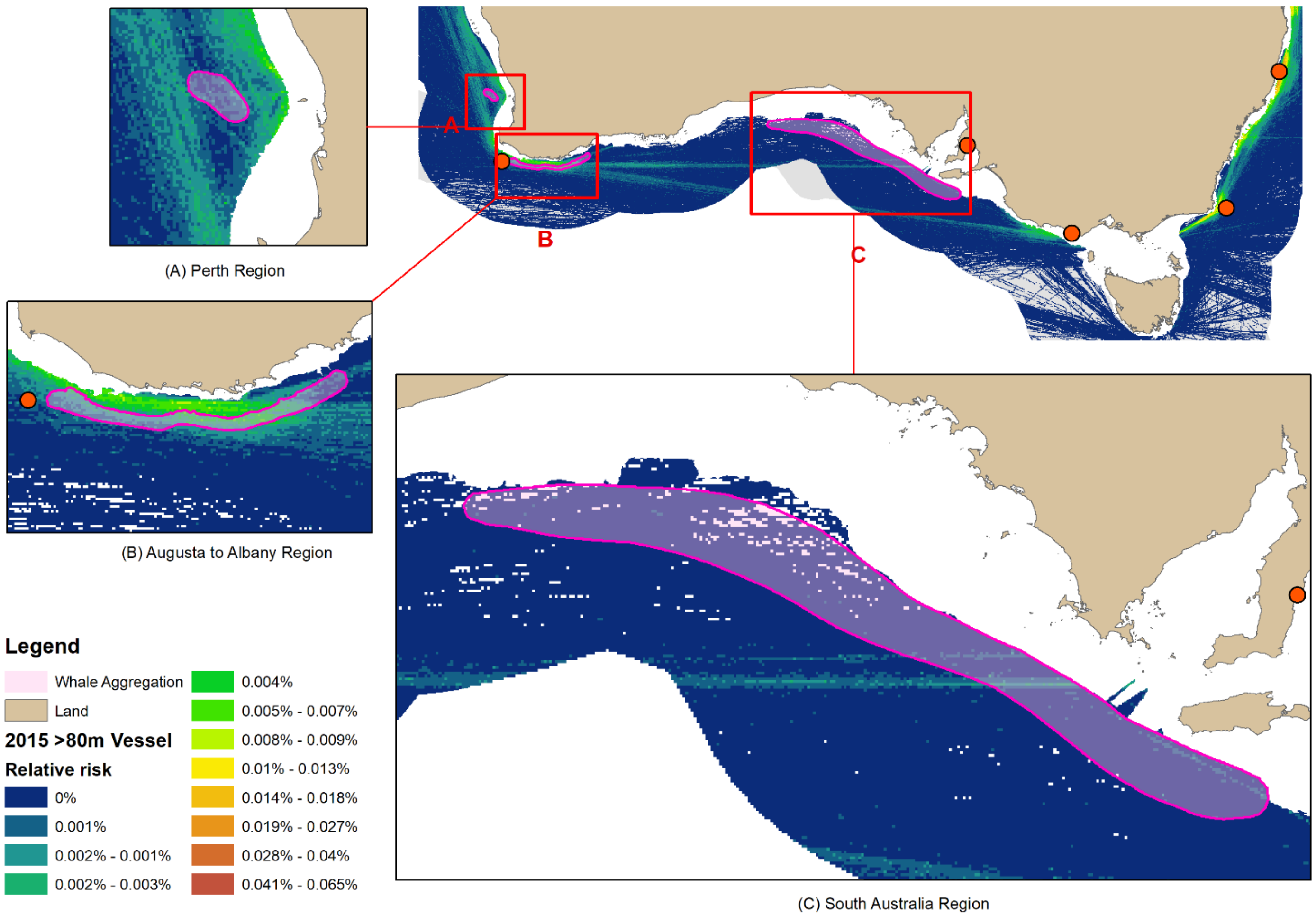


Figure 74 Relative risk of a fatal collision in sperm whale aggregations (assuming uniform density within & across aggregations) for large (>80m) AIS equipped vessels in 2015 (Aggregations supplied by DoEE 2015), with historical vessel strike locations shown (red circles)

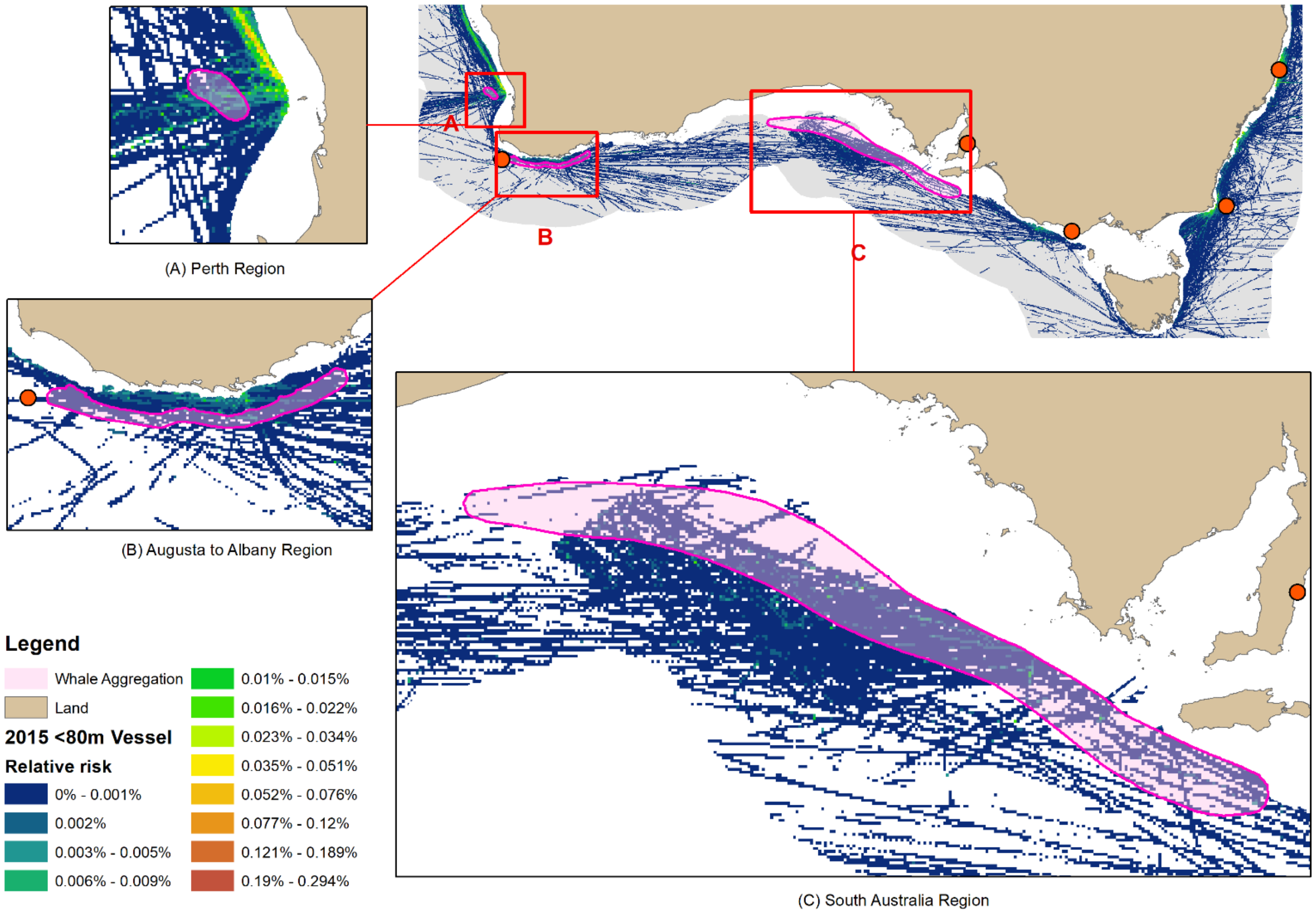


Figure 75 Relative risk of a fatal collision in sperm whale aggregations (assuming uniform density within & across aggregations) for small (<80m) AIS equipped vessels in 2015 (Aggregations supplied by DoEE 2015), with historical vessel strike locations shown (red circles)

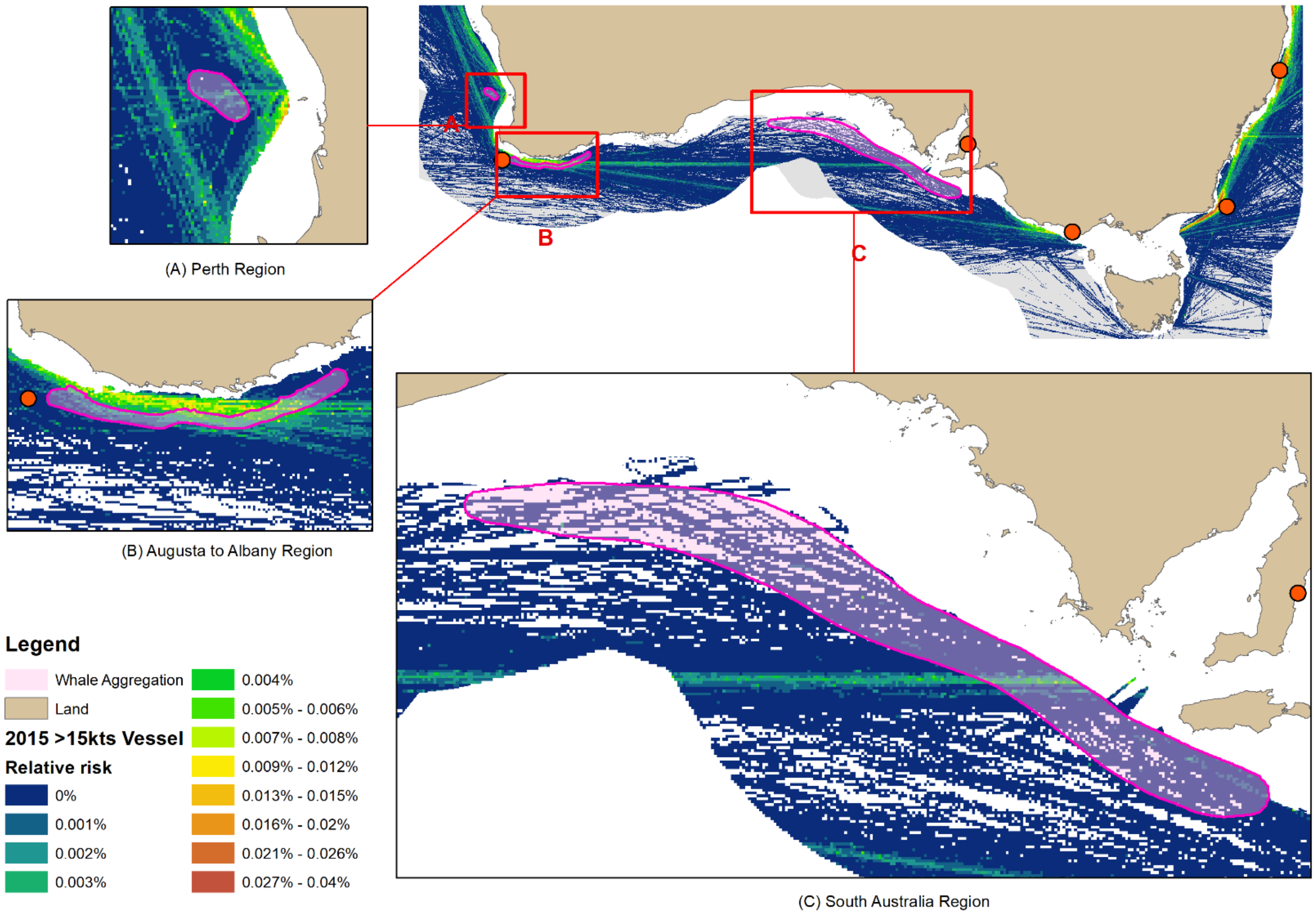


Figure 76 Relative risk of a fatal collision in sperm whale aggregations (assuming uniform density within & across aggregations) for fast moving (>15kts) AIS equipped vessels in 2015 (Aggregations supplied by DoEE 2015), with historical vessel strike locations shown (red circles)

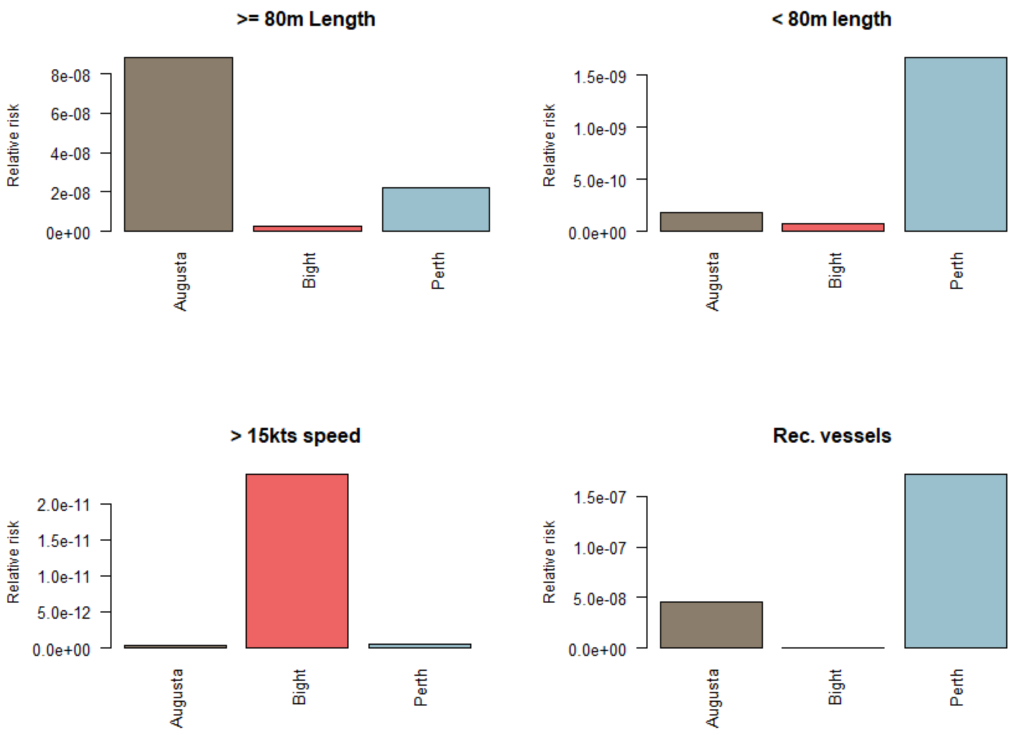


Figure 77 Total relative (using relevant risk metric from Table 15) for each Sperm whale aggregation area for various vessel data sources, standardised by aggregation areas m^2

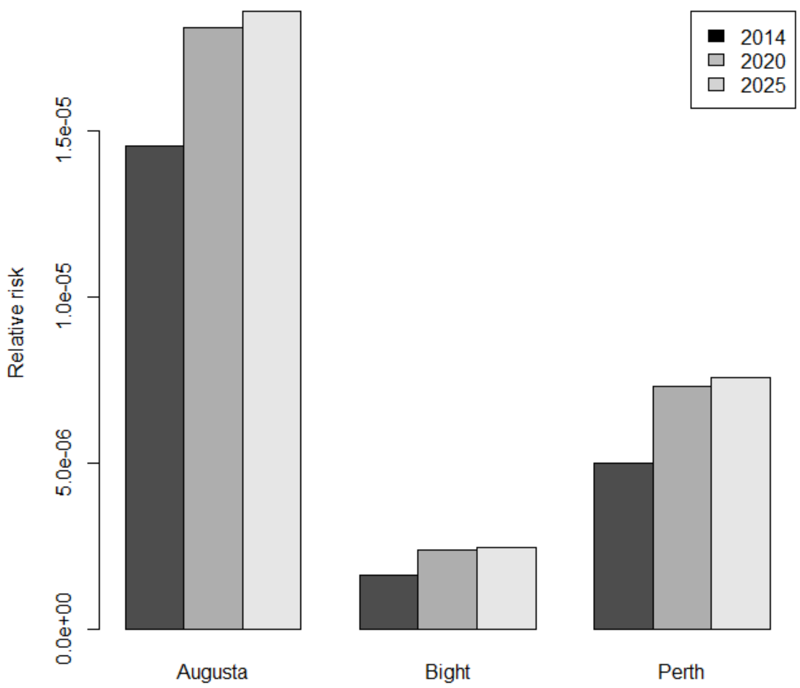


Figure 78 Projected change in total co-occurrence risk in each sperm whale aggregation for all AIS equipped shipping standardised by aggregation area (m^2)

7.4.3 Assumptions and caveats

Assumptions 13 Assumptions and caveats for risk analysis of Sperm whales

The following assumptions were made:

- AIS assumptions and caveats as per Section 5.1.4. The main repercussions for the risk maps are:
    - The smaller vessels are less represented in the AIS data, therefore, the <80m vessel risk maps will not be representative of the risk from all vessels <80m and will be under-estimated.
- Risk Metric assumption as per Section 3.2.3

The aggregation and range areas provided by DoEE via the BIA should not be considered to be complete and are indicative only.

A complete list of caveats and restrictions related to these BIA data is available at the link below[22].

7.4.4 Discussion/Summary

Conclusion I Conclusions for Sperm Whales

Sperm whales have a deep-water distribution resulting in larger ships (>80m) being the main risk rather than smaller vessels (<80m) and recreational vessels

Due to not having animal density or abundance of aggregations, the results cannot take into account differing spatial densities of the animals. However, there was some general indications of where relative risk is potentially higher.

Larger size (>80m) AIS equipped vessels

The **Augusta to Albany** Region had the highest relative risk per m^2 relative to the other aggregations (see Figure 74). There is also a shipping lane passing through the **South Australia region**.

Smaller size (<80m) AIS equipped vessels

The region with indications of having a higher relative risk than the other aggregation was the **Perth region** (Figure 75).

Fast moving (>15kts) AIS equipped vessels

For fast vessels there was little activity through all 3 regions (Figure 76).

[22] Available at: http://www.environment.gov.au/fed/catalog/search/resource/details.page?uuid=%7B2ed86f5a-4598-4ae9-924f-ac821c701003%7D

So far, we have only been considering shipping inside the defined aggregation areas. However, it should be noted that animals must travel to and from these aggregations and all of the aggregations are to some extent surrounded by vessel routes.

Recommendations to improve risk analysis

More distribution information and relative aggregation abundances to allow better quantification of risk.

7.5 Dugong

7.5.1 Data source

The dugong sighting data was sourced from the dugong aerial survey database, which has been compiled as part of a project funded by the Australian Marine Mammal Centre (AMMC). It currently contains data from 54 aerial surveys for dugongs in nine regions along the Australian coast since 1984 including: Shark Bay (WA), Exmouth (WA), Pilbara (WA), Gulf of Carpentaria (NT/QLD), Torres Strait, Northern Great Barrier Reef (QLD), Southern Great Barrier Reef (QLD), Hervey Bay (QLD), and Moreton Bay (QLD). The database has been made accessible to the general community via an open access online data hub based at James Cook University via https://dugongs.tropicaldatahub.org/. The database facilitates future collaborations and accommodates efficient incorporation of new research findings. Information on dugong distribution, habitat use and relative abundance are easily accessible to managers and other stakeholders for their long-term use.

At present due the limited survey coverage in Western Australia we have focused only on the dugongs in Queensland. Western Australian analysis for the specific areas where data is available could be done in future. The dugong density models used in the risk assessment were derived based on the methodology outlined in Grech & Marsh (2007) and provided by Marsh & Sobtzick (2015).

Given dugongs usage of seagrass beds Section 8 is also relevant and may be useful for a more national view.

7.5.2 Risk maps

The animal range and aggregations were used in conjunction with the AIS data density and recreational boat model to produce various risk maps (see Table 16).

Table 16 Summary of data sources and main mapping for Dugong risk analysis

Dugong Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps	Figures
Habit model (See Section 4.1) Source: Marsh & Sobtzick 2015 (see Section 7.5.1)	Vessels >15kts speed	2013-2015 AIS Data (See Section 5.1)	Per year 2013-2015 (only 2015 shown in this report)	1/30° 1/2°	Relative risk of a collision[23] (See Section 3.2.2)	Core area (at 1/2°) and Higher risk areas (at 1/30°)	Figure 79
	Recreation al Vessels	See Section 5.2	Single hypothetical season	1/10°	Relative co-occurrence	Core area (at 1/2°) and Higher risk areas (at 1/10°)[24]	Figure 80

[23] We have no probability of fatality curves for dugongs so we only calculated risk of collision.
[24] As the recreational vessel model has much greater uncertainty we examine at larger grid size than the AIS data.

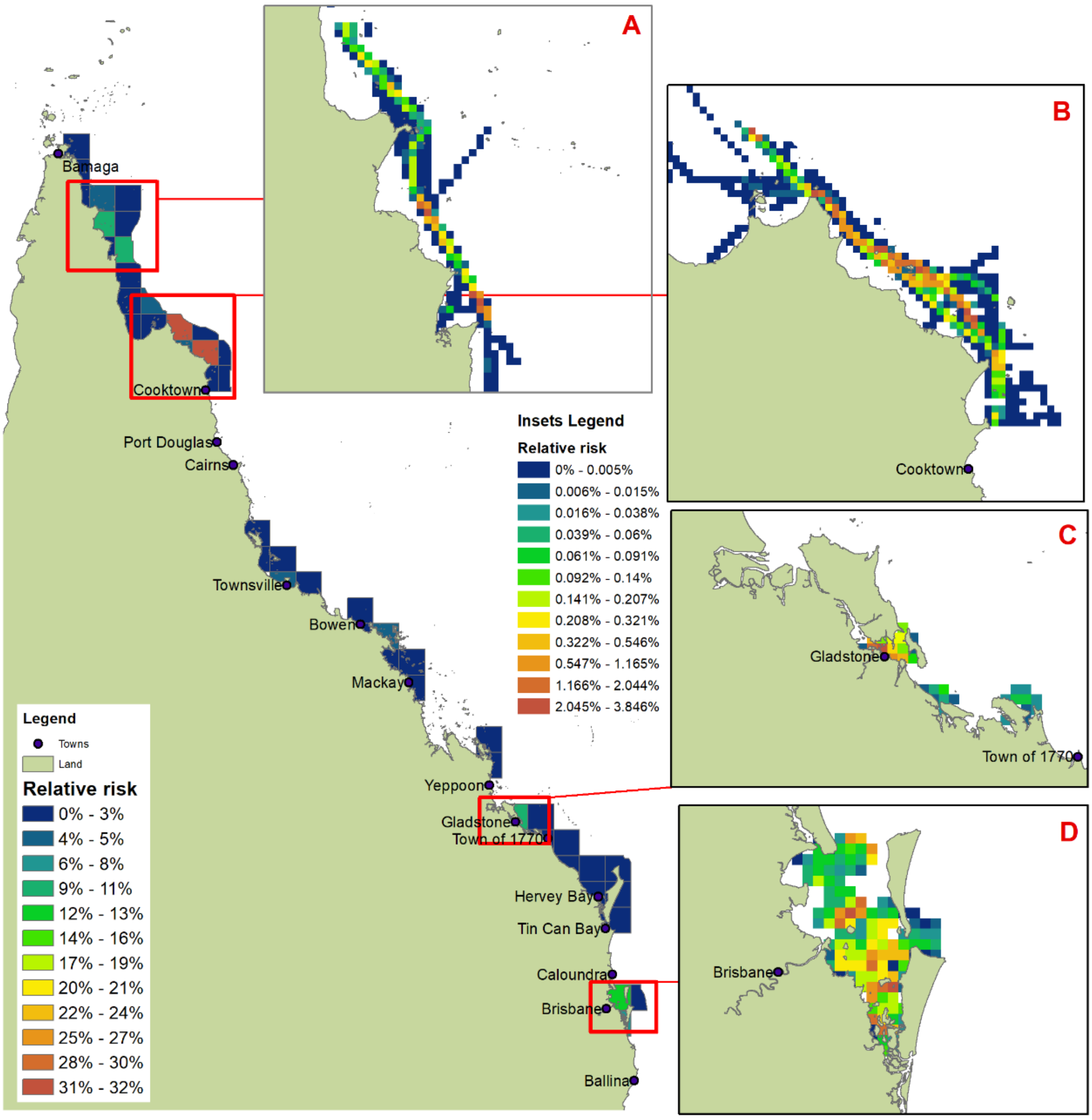


Figure 79 Relative risk of a collision between Queensland Dugongs and fast moving (>15kts) AIS equipped vessels in 2015

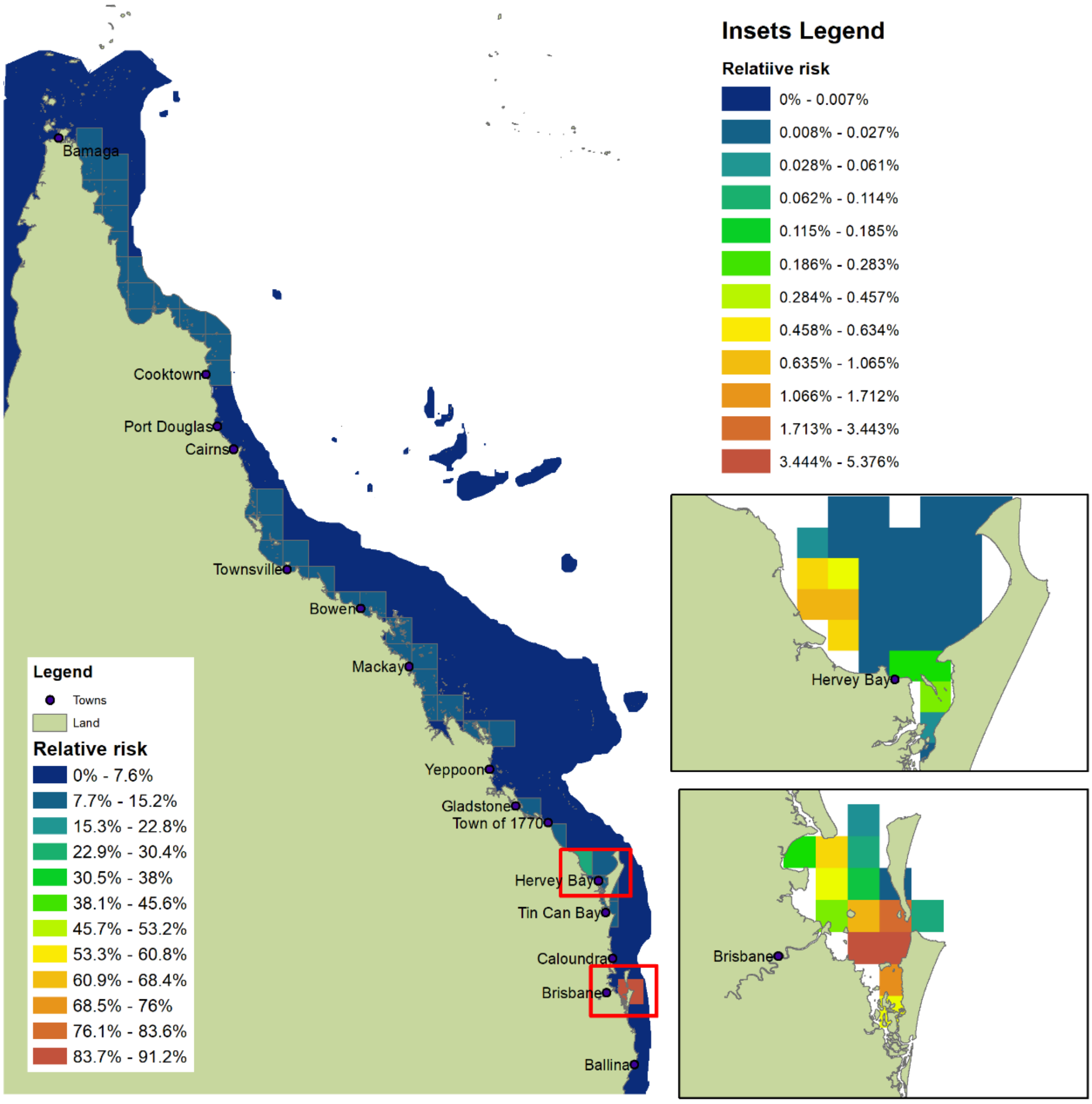


Figure 80 Relative risk of co-occurrence between recreational vessels and Queensland Dugongs

7.5.3 Assumptions and caveats

Assumptions 14 Assumptions and caveats for risk analysis of Dugongs

The following assumptions were made:

- AIS assumptions and caveats as per Section 5.1.4. The main repercussions for the risk maps are:
    - The smaller vessels are less represented in the AIS data. Therefore, the vessel risk maps will not be representative of the risk from all vessels and will under-estimate the total risk.
- Risk Metric assumption as per Section 3.2.3
- Densities in the models we had access to were categorised into None (4; 0); Medium (0.0000001 - 0.25); High (0.25 - 0.5); and Very High (>0.5). To estimate relative risk, we need to quantify the difference between categories. At present we do not have average density so we set them to midpoints of 0, 0.05, 0.3 and 1. This will not be exact since actual mean density of each category are what is required. So the answers will be biased especially in the 'Very High' grid cells.

7.5.4 Discussion/Summary

Conclusion J Conclusions for Dugongs

Based on this preliminary analysis for the East coast:

Fast moving (>15kts) AIS equipped vessels

Indications are regions of higher relative risk on the Queensland coast are **Far North Queensland, Gladstone** and **Moreton Bay** (See Figure 79).

Recreational vessels

The uncertainty and assumptions of the recreational vessel distribution model mean that we are wary of making any finer scale inference. That being said, indications are that the areas of highest relative risk on the Queensland coast are **Hervey Bay** and **Moreton Bay** (See Figure 80).

Recommendations to improve risk analysis

- Better recreational vessel models
- Obtain raw density for dugong distribution models and expand spatially coverage with any data/models from Northern and Western Australia.
- Fine-scale examination of areas of concern (For example based on maps similar to those in Appendix F).

7.6 Green turtle

7.6.1 Data source

To calculate national vessel strike risk for green turtles we used a modified version of the national model developed by Hayes et al. (2012) which is based on the 299 green turtle observations in the SPRAT database up to 2012. Hayes et al. (2012) presented a number of models and, of these, we chose to use the RuleFit model (Friedman and Popescu 2008) as this appeared to provide the most believable fit. For this project we modified and refitted the model to better suit our application by focusing on position around coast line as the spatial covariate, rather than longitude and latitude. Furthermore, due to potential sampling bias and our focus on coastal waters, we removed depth from the analysis. The result is shown in Figure 81.

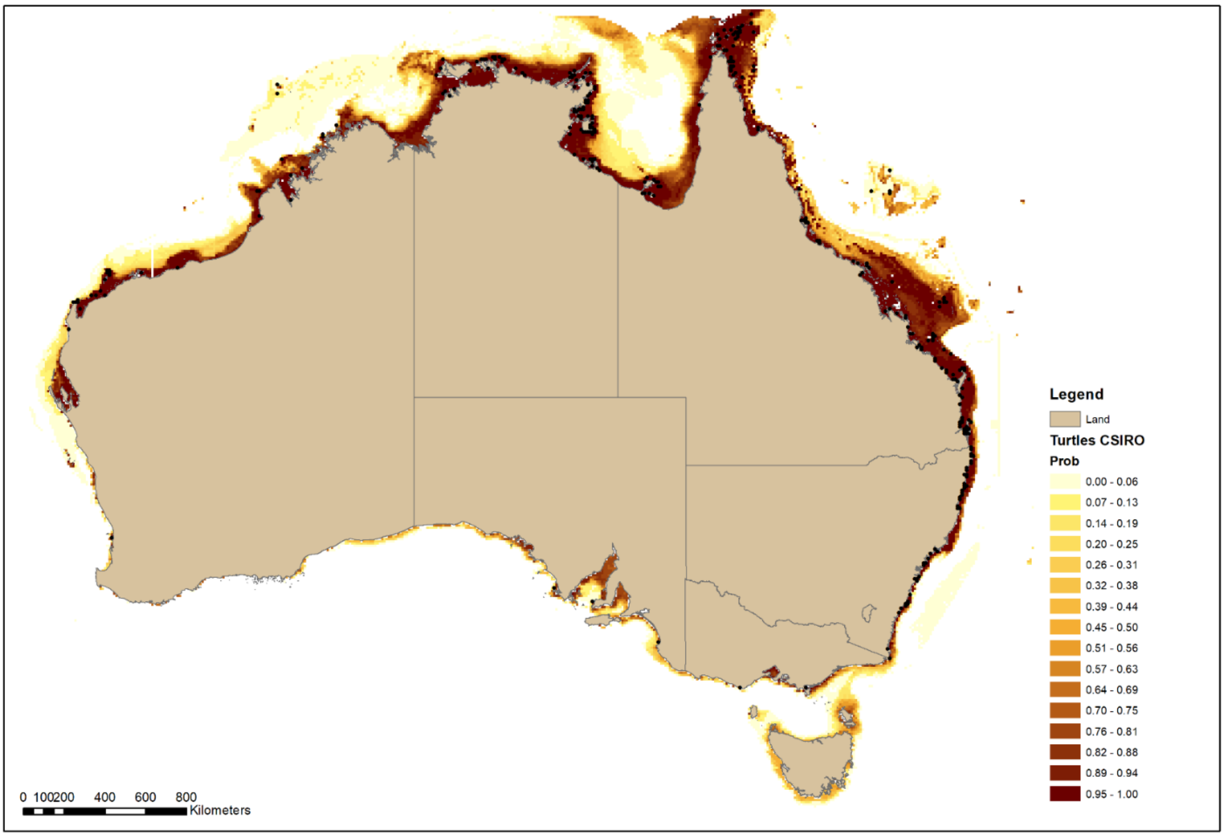


Figure 81 Average probability of suitable habitat predicted for Green turtle using a modified version of RuleFit model.

7.6.2 Risk maps

The distribution model in Figure 81 was used in conjunction with the AIS data density for fast moving vessels and recreational boat model to produce various risk maps (see Table 17). We can compare the relative risk across broad-scale regions e.g., states.

Table 17 Summary of data sources and main maps for Green Turtle risk analysis

<table>
<tr><th>Turtle Information</th><th>Type</th><th>Source Data</th><th>Temporal Maps</th><th>Spatial Resolutions</th><th>Risk Model</th><th>Maps</th><th>Figures</th></tr>
<tr><td rowspan="2">Habit model (See Section 4.1) Hayes et al 2012- Modified by Peel (see Section 7.6.1)

Data Source: SPRAT</td><td>Vessels >15kts speed</td><td>2013-2015

AIS Data (See Section 5.1)</td><td>Per year 2013-2015 (only 2015 shown in this report)</td><td>1/30°

1/2°</td><td>Relative risk of a collision[25] (See Section 3.2.2)</td><td>Core area (at 1/2°) and Higher risk areas (at 1/30°)</td><td>Figure 82</td></tr>
<tr><td>Recreational Vessels</td><td>See Section 5.2</td><td>Single hypothetical season</td><td>1/10 °</td><td>Relative co-occurrence</td><td>Core area (at 1/2°) and Higher risk areas (at 1/10°)[26]</td><td>Figure 83</td></tr>
</table>

[25] We have no probability of fatality curves for turtles so we only calculated risk of collision.
[26] As the recreational vessel model has much greater uncertainty we examine at larger grid size than the AIS data.

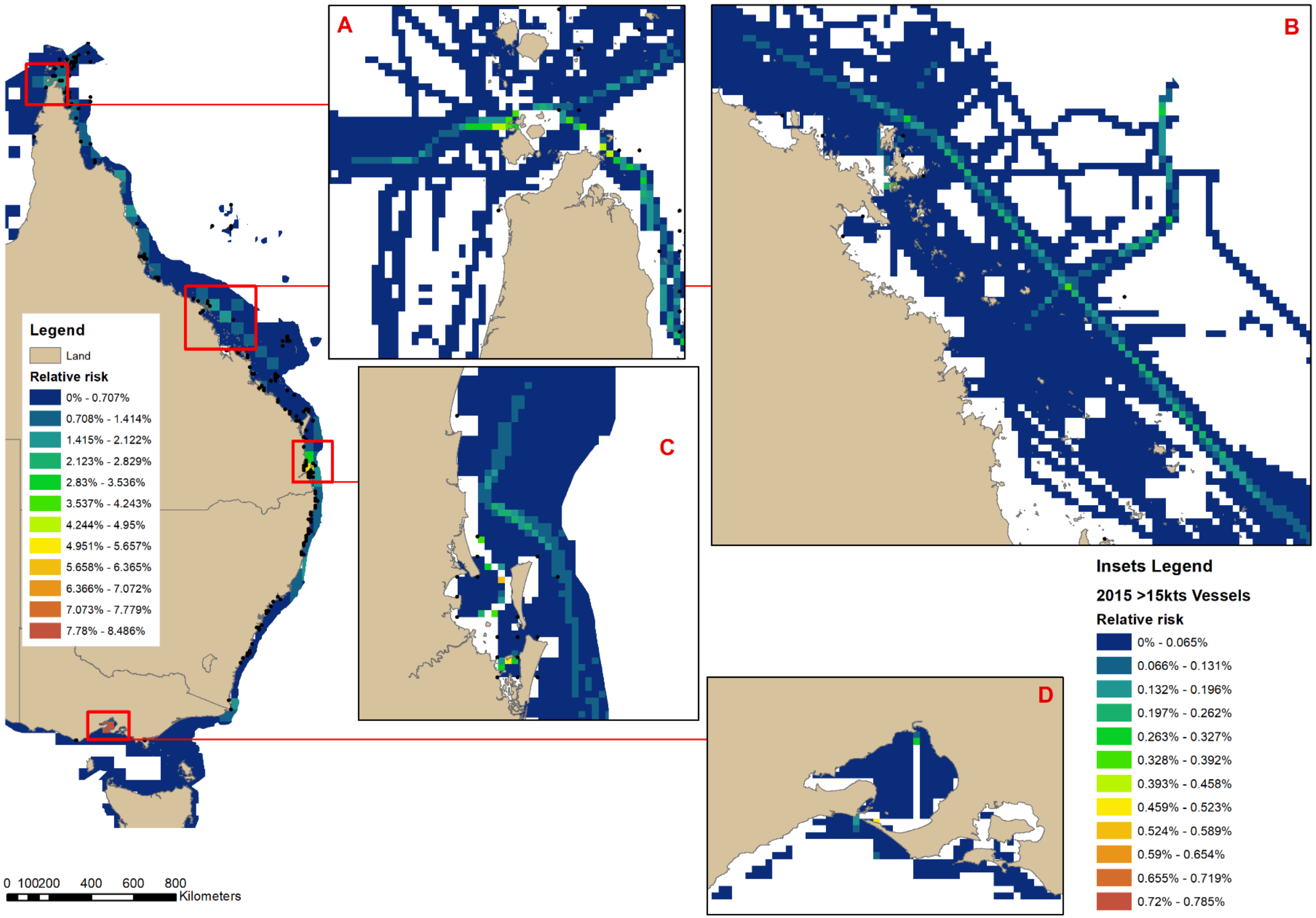


Figure 82 Relative risk of a collision between Green Turtles and fast moving (>15kts) AIS equipped vessels in 2015

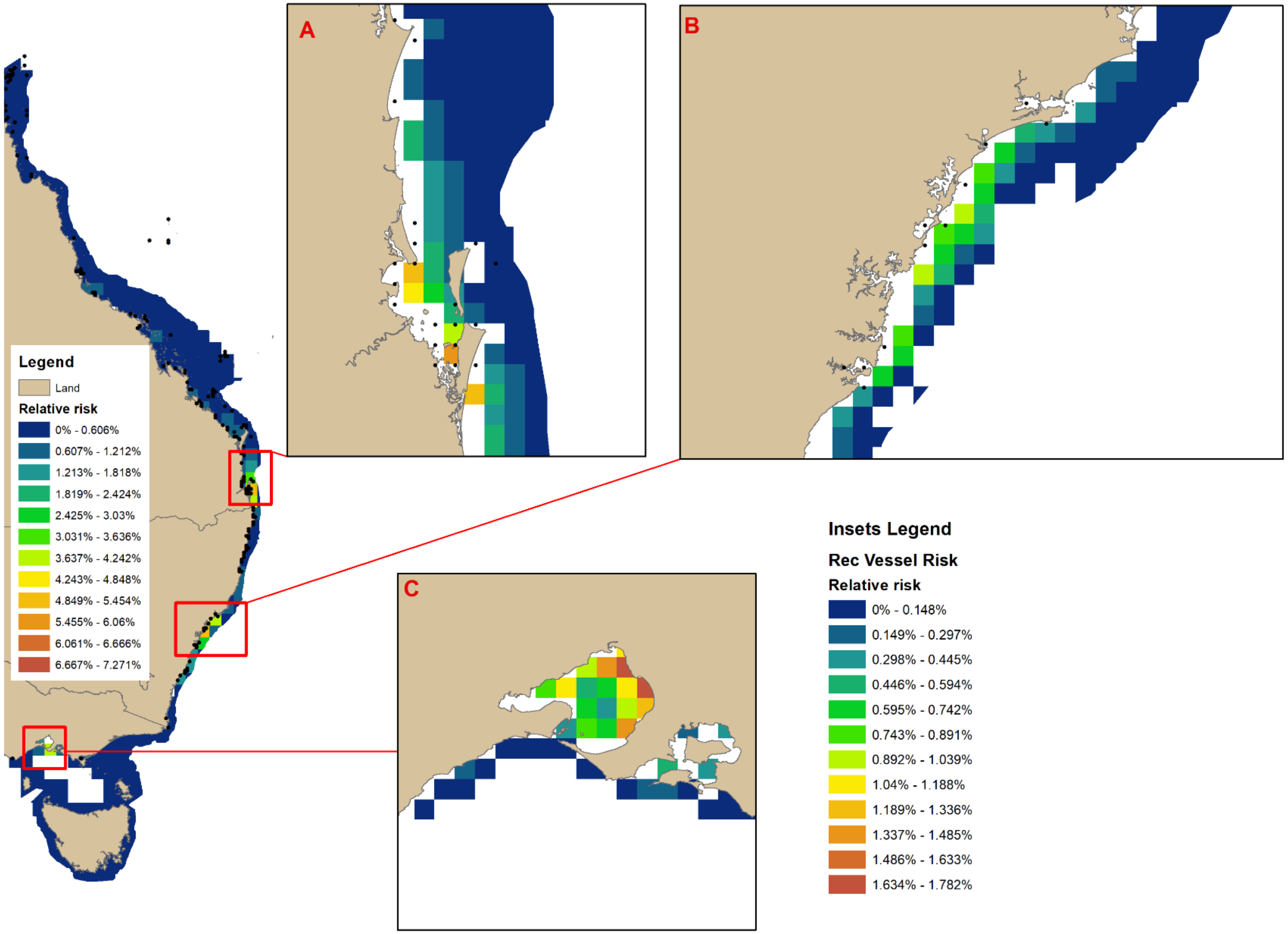


Figure 83 Relative risk of co-occurrence between Green Turtles and recreational vessels

7.6.3 Assumptions and caveats

Assumptions 15 Assumptions and caveats for risk analysis of Green turtles

The following assumptions were made:

- The turtle distribution model is based on presence only data and some assumptions are made about the distribution of the absences. See Hayes et al. (2012) for full details. It should be noted that for the purpose of this report, we refitted the model with a parametrisation of the spatial terms to be just distance along Australian coast and since we are interested in shallower waters and given that most of the data are on coast, we did not include the depth term.
- AIS assumptions and caveats as per Section 5.1.4. The main repercussions for the green turtle risk maps are:
    - The smaller vessels are less represented in the AIS data. Therefore, the overall vessel risk maps will not be representative of the risk from all vessels and will be an under-estimate.
- The recreational vessel risk map has the assumptions and caveats listed in Section 5.2.1.
- Risk Metric assumption as per Section 3.2.3

7.6.4 Discussion/Summary

Conclusion K Conclusions for Green turtles

Fast moving (>15kts) AIS equipped vessels

Indications are regions of higher relative risk are **Far North Queensland**, Shipping lane offshore from **Gladstone, South-East Queensland, and Melbourne** (see Figure 82). The Melbourne result was surprising and is possibly due to the co-occurrence model having issues when there is a high density of vessels and a small number of animals. This may be related to when the relationship between density and risk is no longer linear and therefore the result may be positively biased.

Recreational vessels

The uncertainty and assumptions of the recreational vessel distribution model and animal distribution model mean that we are wary of making any fine scale inference. However, broadscale indications were that the highest risk is in Queensland. For example, the Queensland coast had a total risk of the order of 10x that of the WA coast (See Figure 82).

Recommendations to improve risk analysis

- Improved recreational vessel models
- Further green turtle distribution data (inclusion of newer data) and more validation of the model/distribution.
- Fine-scale examination of areas of concern (For example based on maps similar to those in Appendix F).

8. SEAGRASS

Given the difficulty building national maps for turtles and dugongs, one alternative is to look at the co-occurrence of habitat and vessel traffic. Specifically, we can look at co-occurrence of vessels traffic and identified seagrass beds[27]. Seagrass bed data is readily available and can potentially provide greater insight into risk. However, since the actual animal density is unknown it does not give an indication of actual risk but rather indicates the potential for risk or interaction. How relevant seagrass is to vessel strike risk will obviously depend on the species and their affinity and use of seagrass beds.

8.1.1 Data source

For this initial analysis we used the CAMRIS data set (CSIRO 2015)

[27] Based on discussion and suggestion by Karen Arthur (DoEE)

8.1.2 Risk maps

The seagrass data was used in conjunction with the AIS data density to produce a risk maps (see Table 18). The approach we took was to estimate the risk in each seagrass bed. Some of the seagrass beds are quite small and so the scale we need to analyse at is quite fine e.g. grid cells of 1/500°. However, computing at the scale is time consuming. We decided to first estimated risk at 1/30° nationally, to get the aggregated risk in each seagrass bed. Doing the initial calculations at the 1/30° resolution had 2 advantages

1) The risk calculated for each seagrass bed didn't just include the vessel traffic in the bed but tended to include traffic near and around the bed.

2) Computationally the 1/30° scale grid on the national scale was much more feasible than using the 1/500°

Once we had a risk value for each seagrass bed we ranked then examined the highest 20 beds nationally at the finer 1/500° scale.

Table 18 Summary of data sources and mapping for seagrass beds

Seagrass Information	Type	Source Data	Temporal Maps	Spatial Resolutions	Risk Model	Maps	Figures
Polygons	All Vessels Vessels >15kts speed	2013-2015 AIS Data (See Section 5.1)	Per season (Aug-Sep) 2013-2015 (only 2015 shown in this report)	Identified surrounding areas by aggregating risk at 1/30°	Relative risk of a collision (See Section 3.2.2)	Higher risk areas (at 1/500°)	Figure 84

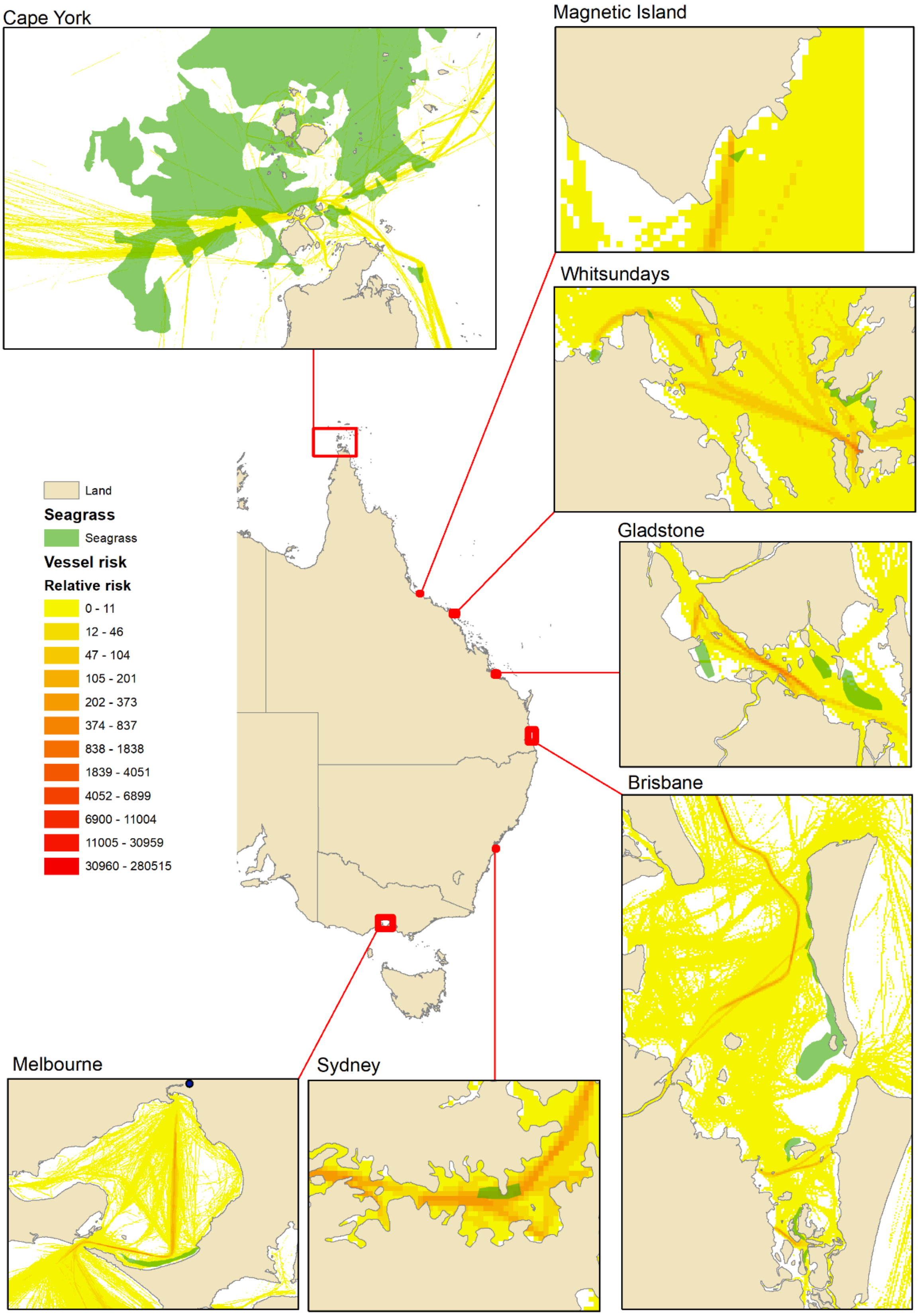


Figure 84 Selected seagrass beds where surrounding shipping relative risk of collision was highest for vessels travelling > 15 knots

8.1.3 Assumptions and caveats

Assumptions 16 Assumptions and caveats for risk analysis of Green turtles

The following assumptions were made:

- All the caveats associated with the original seagrass map data ()
- That the seagrass distribution has not changed since the seagrass maps were produced.
- That the main concern would be vessels travelling at 15 knots or greater. This value is rather arbitrary. However, in general many of the beds identified in the top 20 are the same as those identified when all vessels are included regardless of speed. The maps and analysis can easily be repeated for different speeds.
- This analysis is based on AIS equipped vessels only. It is obvious due to the shallow coastal nature of seagrass beds that smaller recreational vessels (that generally do not have AIS) would be very important to consider. As noted in Section 5.2.1 the current recreational boat model we have is only to be used at very broad scales so we decided not to use it in this fine-scale analysis.
- The seagrass beds vary considerable in size. We did not take size into account but rather just looked at total risk. It may be valuable to explore other metrics that take area into account such as risk per square metre.
- AIS assumptions and caveats as per Section 5.1.4. The main repercussions for the green turtle risk maps are:
    - The smaller vessels are less represented in the AIS data. Therefore, the overall vessel risk maps will not be representative of the risk from all vessels and will be an under-estimate.
- Risk Metric assumption as per Section 3.2.3

8.1.4 Discussion/Summary

Conclusion L Conclusions for seagrass

Fast moving (>15kts) AIS equipped vessels

Indications of regions of higher relative risk are **Cape York**, a small bed off **Magnetic Island**, a few beds in an around the **Whitsunday Island area, Gladstone, Moreton Bay**, a bed in **Sydney Harbour**, and in **Port Phillip bay** (Figure 84)..

Interestingly, all the higher risk areas were in Eastern Australia.

Recommendations to improve risk analysis

- Improved recreational vessel models
- Updated seagrass bed maps, particularly in the identified areas of higher relative risk
- Further examination of how to estimate total risk per bed, e.g. scaling to get surrounding vessels, how to handle the difference in size e.g. look at total risk or risk per square metre.

9. MODELLING OF SHIP NOISE

As ship traffic and the size of commercial ships continues to increase worldwide, noise pollution and its impact on underwater fauna is becoming a concern. There is increasing concern that commercial shipping contributes to a significant portion of the underwater noise generated by human activity which has been driven by globalisation and marine transport network expansion, urbanisation, and a greater global demand for natural resources. For example, the behaviour and breeding patterns of fish and marine mammals have been found to be negatively affected by anthropogenic underwater radiated noise (Rolland et al., 2012). This has raised interest in gaining an improved and quantitative insight into underwater noise caused by ship traffic.

This component of the project provides the initial effort for mapping temporal, spatial, and spectral characteristics of ship noise from large commercial vessels (>80m in length) in Australian waters. These maps use the distribution, density, and acoustic characteristics of large ships to develop first-order estimates of their contribution to ambient noise levels. The noise mapping of large ships in this project is preliminary work that builds on similar work undertaken in Canada (Erbe et al. 2012). This will provide a proof of concept that a framework can be developed to produce a national ship noise map at both a broad and fine scale resolution, with the aim of identifying areas of potential impact on marine fauna and where further focussed research may be undertaken.

9.1 Ship source level spectra measurements

Estimates of the noise source spectra of ships were obtained using geo-referenced AIS data provided by AMSA and acoustic data from the Integrated Marine Observing System (IMOS) infrastructure from an acoustic receiver deployed near the major shipping channel past the Perth Canyon. Measurements were made from 47 ships in 2014 and 45 ships in 2016 travelling within 3km of the acoustic receiver in which no other ships were within 30km of the acoustic receiver. For each passage, ship-to-hydrophone transmission loss (TL) spectra were computed by sound propagation modelling using bathymetry, sound speed profiles, seabed characteristics and AIS data providing information on each ship’s position to determine range to the hydrophone. These TL spectra were then added to the received noise spectra to estimate the free field source level (SL) spectra for each ships pass.

Source level spectra were calculated for five different ship size classes (Figure 85), which indicates higher source levels of ship noise are produced as vessel size increases. The 1/3-octave band source spectra represent mean SL, in terms of total radiated sound power, for each category of vessel.

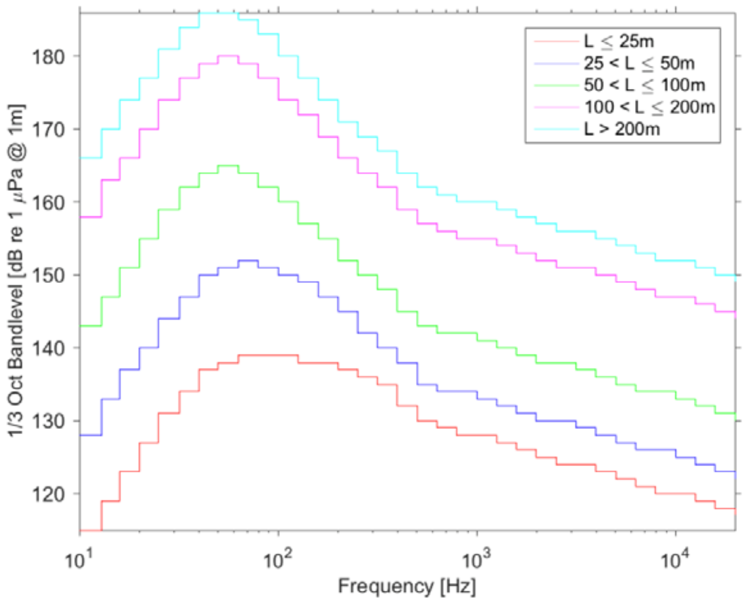


Figure 85 Estimated source level spectra of ships recorded using the IMOS recorders for five size classes of vessel (n = 92 vessels)

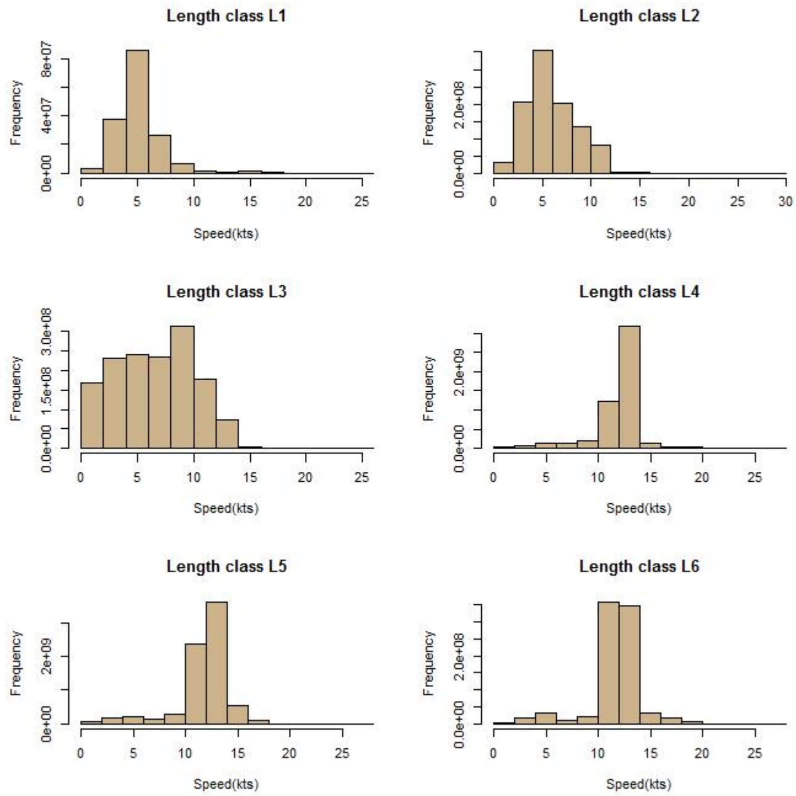


Figure 86 Distribution of estimated vessel speeds for vessels within six different size classes from AIS data; L1 = <10m, L2 = ≤25m, L3 = 25-50, L4 = 50-100m, L5 = 100-200m and L6 = ≥200m.

9.2 Acoustic modelling of cumulative ship noise

Cumulative Sound Exposure Levels (SELcum) of shipping traffic in Australian waters was undertaken over a one year period (Sept. 2015 to Oct 2016) within the Australian Exclusive Economic Zone. SELcum is the total sound energy of shipping traffic at any location in space integrated over a specified time period, which in this case is one year. Essentially, cumulative ship noise maps were developed around Australia using the Perth Canyon source spectra as the source level for different vessel type categories. Sound propagation models were then run cumulatively, integrating the time spent by ships within a grid cell over the one-year period.

Received levels of ship noise were computed in 1/3 octave bands from 10 Hz to 2 kHz on a 10x10 km grid over a 100 km radius from each source cell of the ships location for 31,038,563 AIS positions from 11,143 vessels around Australia. To propagate ship noise through the marine environment, a geometric transmission loss model was applied decreasing the noise level by 20 log10(range/m) until the range equalled the maximum water depth along the specific source-cell to receiver-cell transect, and by 10 log10(range/m) thereafter. A land mass mask was applied within the sound propagation models using Geoscience Australia coastline shapefiles and bathymetry was used from the Etopo2 database to populate each grid cell with water depth. SEL were computed by adding 10 log T to RL, where T was the time (in seconds) a vessel type spent in each source cell. Received energy was then integrated over all ships for the 12 months. The resulting map of cumulative underwater acoustic energy from all ships over a 12-month duration (Figure 87) shows noise levels were highest (>185dB) on the eastern coast around Melbourne, Sydney to Brisbane and the Great Barrier Reef and off the NW coast of Western Australia.

The results from the ship noise modelling has demonstrated the potential for using simple and readily accessible transmission models as a starting point, to provide an accurate representation of shipping noise within the marine soundscape. The models provide a quantitative framework for simulating the acoustic consequences of proposed industrial developments in Australia, such as expansion of shipping ports and associated traffic around ports related to natural resource exports e.g. Queensland and NW Australia. The models allow quantitative forecasting and hindcasting to assess how trends in shipping may translate to trends in noise levels. Most importantly, the predictions can be overlaid on marine wildlife distribution maps to evaluate impacts of anthropogenic noise on the critical habitats of vulnerable species, such as how it relates a species hearing sensitivity using audiograms. This will lead to better integration of anthropogenic ship noise into marine spatial planning.

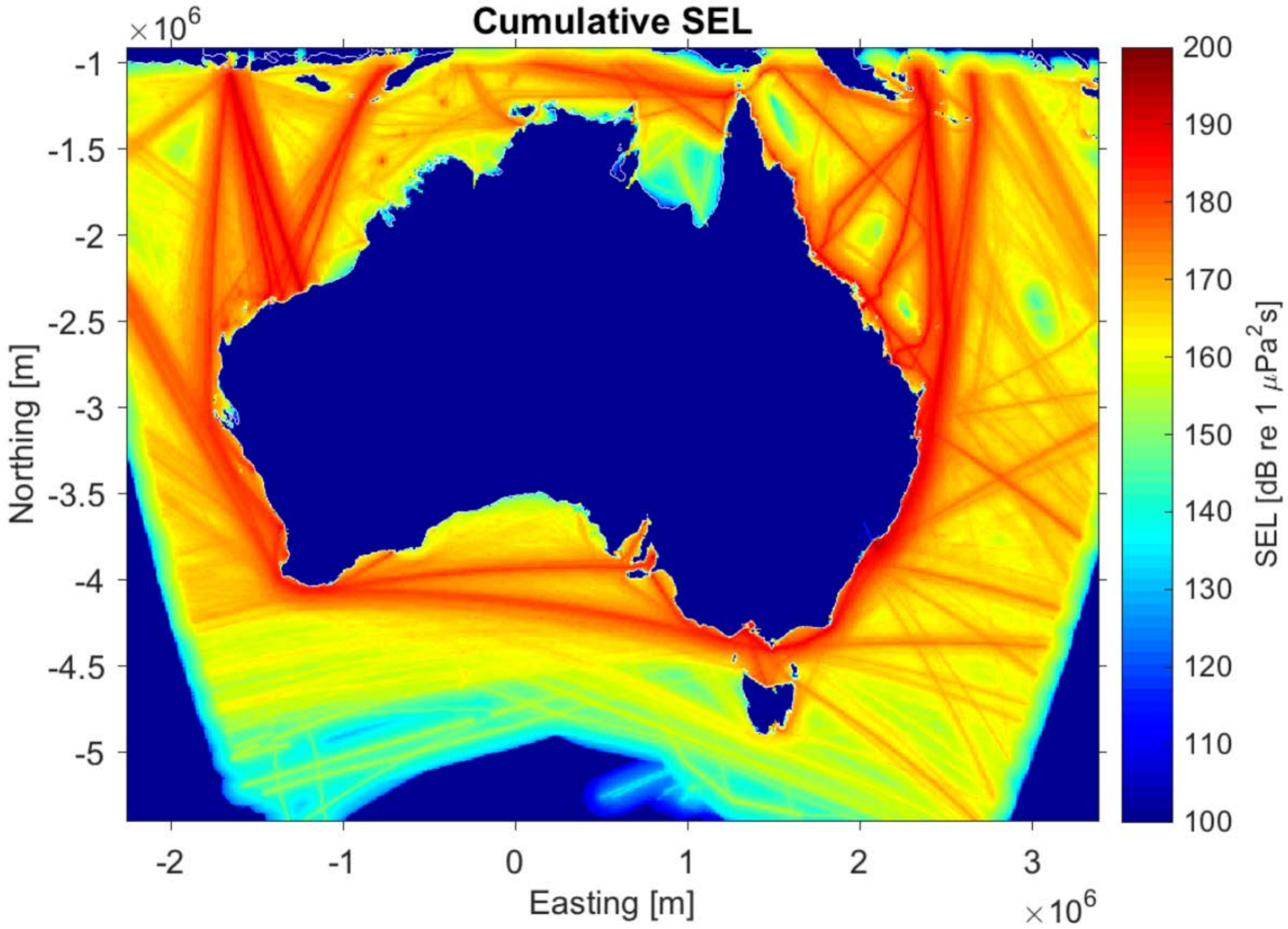


Figure 87 Cumulative sound exposure level of all ship size classes over one year, Oct 2015-Sept 2016

9.3 Workshop on characterising underwater shipping noise in Australia

A workshop on characterising underwater shipping noise in Australia was convened in Canberra at the offices of Geoscience Australia on Thursday 2nd November 2017. The objective of the workshop was to present the initial proof of concept national ship noise maps and discuss the future direction of ship noise research in Australia in relation to stakeholder needs. Details of the workshop are outlined in Peel et al. (2017). The specific aims of the workshop were to:

1. Provide a brief overview of noise mapping projects overseas and the underlying management imperatives;

2. Present preliminary findings of shipping noise maps from the current NESP C5 project (i.e., this project);

3. Identify management priorities related to underwater noise provided by relevant stakeholders;

4. Provide an overview of the future proposed NESP shipping noise project; and

5. Discuss future direction and development of noise maps for Australia

The workshop was attended by representatives of relevant stakeholder organisations including Australian Antarctic Division, Australian Maritime Safety Authority, CSIRO, Defence Science and Technology Group, Department of Environment and Energy, Geoscience Australia, IMOS, Maritime Safety Queensland, National Environmental Scientific Program and Parks Australia.

An important outcome in relation to the aims of the workshop was the identified need to align the work on shipping noise in Australia with each stakeholders' priorities. This requires research outputs to be aligned with management needs from the initial stages of the research so that the uptake of the outputs can be maximised. It was identified that the project deliverables need to be tailored for individual stakeholders due to their different requirements and policies. Furthermore, fine-scale mapping that requires dedicated resources of time and money needs to identify the user and work collaboratively with that stakeholder to deliver the desired product. It was also identified that the research on acoustic modelling of shipping noise is highly complex/scientific and there needs to be considerable attention given to interpretation of the project outputs to link the gap between the science and the application by managers/users.

An overview of future proposed research on characterising shipping noise was outlined

9.4 Conclusion/Summary

Conclusion M Summary and key ideas of modelling of ship noise

As proof of concept, a cumulative noise map of large ships has been developed for the entire Australian Exclusive Economic Zone. This has identified the potential for using simple and readily accessible transmission models as a starting point, to provide an accurate representation of shipping noise within the marine soundscape. This will ultimately allow comparisons with marine fauna distribution maps or Marine Parks/Reserves, to better integrate anthropogenic noise into marine spatial planning.

Two major priorities identified by stakeholders for the outputs of noise modelling are:

1. Validation of ship noise models and maps: to provide confidence in the accuracy of the noise models and associated error from modelled outputs

2. Quantification of natural ambient noise: to properly interpret the noise modelling results, it is important to quantify natural ambient noise to provide context to anthropogenic noise.

The project outputs need to be tailored for each stakeholder due to their unique requirements and this also requires managers to properly communicate their requirements. Critical to this manager/science interface will be effort invested in advising on the interpretation of the complex and scientific nature of noise modelling.

10. MISCELLANEOUS OUTPUTS

10.1 Australian Vessel Strike Incidents Analysis

An analysis of the historical vessel strike data (as part of vessel strike evidence collation in Section 2) was incorporated into a paper looking at the challenges of making inference from vessel strike data (Peel et al. 2018).

https://www.frontiersin.org/articles/10.3389/fmars.2018.00069/full

10.2 Conversation article on vessel strike in Australia

To raise awareness of the issue and draw attention during public comment period of the *draft National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna* (Department of the Environment and Energy 2017), an article for the conversation was written

https://theconversation.com/as-australian-shipping-grows-how-can-we-avoid-collisions-with-marine-animals-69562

10.3 Effect of IMO route changes in the GBR

Following on from the work of Peel et al. (2015), a revision was made using updated data and analysis from the current project a paper looking at the effect on vessel strike risk for East coast Humpback whales from changes to IMO shipping routes. This has been submitted to Biological Conservation (Smith et al. *in prep*).

10.4 New method to interpolate tag movement data

The methodology to estimate a distribution from the Humpback whale movement data collected from satellite tags is new and novel and a paper is in preparation (Peel et al. *in prep*).

10.5 Risk assessment of vessel strike review paper

During the project, some time was spent examining the theoretical and methodological aspects of vessel strike risk. The findings and technical guidelines for vessel strike risk assessment are being written in collaboration with Jessica Redfern and TJ Moore (NOAA) into a paper (Peel et al. *in prep*)

REFERENCES

Bauduin, S., Martin, J., Edwards, H. H., Gimenez, O., Koslovsky, S. M., & Fagan, D. E. (2013). An index of risk of co-occurrence between marine mammals and watercraft: example of the Florida manatee. Biological conservation, 159, 127-136. https://www.sciencedirect.com/science/article/pii/S000632071200451X

Bureau of Infrastructure, Transport and Regional Economics (BITRE), 2015, Yearbook 2015: Australian Infrastructure Statistical Report, BITRE, Canberra ACT. https://bitre.gov.au/publications/2015/yearbook_2015.aspx

Cates, K., DeMaster, D. P., Brownell Jr., R.L., Silber, G., Gende, S., Leaper, R., Ritter F. & Panagida, S. (2017). Strategic Plan to Mitigate the Impacts of Ship Strikes on Cetacean Populations: 2017-2020. International Whaling Commission document IWC/66/CC20. https://iwc.int/private/downloads/dr1UJzeCuNpAWs9Xf9caBw/IWC_Strategic_Plan_on_Ship_Strikes_Working_Group_FINAL.pdf

Conn, P. B., & Silber, G. K. (2013). Vessel speed restrictions reduce risk of collision-related mortality for North Atlantic right whales. Ecosphere, 4(4), 1-16. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/ES13-00004.1

CSIRO (2015): Seagrass Dataset - CAMRIS. v1. CSIRO. Data Collection. https://doi.org/10.4225/08/5514852027A1E

Department of the Environment (1998) Australia - Species of National Environmental Significance Database. Bioregional Assessment Source Dataset, http://data.bioregionalassessments.gov.au/dataset/4eff885b-0d68-45e8-b4b1-e3e5448354eb.

Department of Sustainability, Environment, Water, Population and Communities, (2012). Conservation Management Plan for the Southern Right Whale: A Recovery Plan under the Environment Protection and Biodiversity Conservation Act 1999 2011-2021. http://www.environment.gov.au/resource/conservation-management-plan-southern-right-whale-recovery-plan-under-environment

Department of the Environment and Energy (2015). Biologically important areas of regionally significant marine species. http://www.environment.gov.au/marine/marine-species/bias

Department of the Environment and Energy (2017). National Strategy for Reducing Vessel Strike on Cetaceans and other Marine Megafauna. http://www.environment.gov.au/marine/publications/national-strategy-reducing-vessel-strike-cetaceans-marine-megafauna

Erbe, C., MacGillivray, A., & Williams, R. (2012). Mapping cumulative noise from shipping to inform marine spatial planning. Journal of the Acoustical Society of America, 132(5), El423-El428. doi: 10.1121/1.4758779

Fonnesbeck, C. J., Garrison, L. P., Ward-Geiger, L. I., & Baumstark, R. D. (2008). Bayesian hierarchical model for evaluating the risk of vessel strikes on North Atlantic right whales in the SE United States. Endangered Species Research, 6(1), 87-94. https://www.int-res.com/abstracts/esr/v6/n1/p87-94/

Friedman, J. H. and Popescu, B. E. (2008). Predictive learning via rule ensembles. Annals of Applied Statistics, 2(3):916–954. http://www-stat.stanford.edu/˜jhf/R-RuleFit.html

Grech, A. & Marsh, H. (2007) - Prioritising areas for dugong conservation in a marine protected area using a spatially explicit population model, Applied GIS, 3(2): 1-14.

Hayes, K. R., Clifford, D., Moeseneder, C., Palmer, M., & Taranto, T. (2012). National Indicators of Marine Ecosystem Health: Mapping Project. Report prepared for the Australian Government Department of Sustainability, Environment, Water, Population and Communities. https://publications.csiro.au/rpr/pub?pid=csiro:EP132931'

How, J., Coughran, D., Smith, J., Double, M., Harrison, J., McMath, J., Hebiton, B., and Denham, A. (2015) Effectiveness of mitigation measures to reduce interactions between commercial fishing gear and whales. FRDC Final Report 2013/037. *Department of Fisheries Western Australia, Perth. 120pp.* *http://www.fish.wa.gov.au/Documents/research_reports/frr267.pdf*

Marsh, H.; Sobtzick, S. (2015). Dugong Aerial Survey Database. James Cook University. [Database] http://dx.doi.org/10.4225/28/557F7B61ED8E1

Martin, J., Sabatier, Q., Gowan, T. A., Giraud, C., Gurarie, E., Calleson, C. S, & Koslovsky, S. M. (2016). A quantitative framework for investigating risk of deadly collisions between marine wildlife and boats. *Methods in Ecology and Evolution*, *7*(1), 42-50. https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/2041-210X.12447

Peel, D., Kelly, N., Smith J., Childerhouse, S., Moore, T.J., and Redfern, J. (2015). Quantitative assessment of the relative risk of ship strike to humpback whales in the Great Barrier Reef. Final AMMC project (13/46) report. www.marinemammals.gov.au 89pp. https://data.marinemammals.gov.au/grants

Peel, D., Kelly, N., Smith, J.N., and Childerhouse, S. (2016). *Scoping of potential species for ship strike risk analysis.* Report to the National Environmental Science Programme, Marine Biodiversity Hub. *CSIRO. 79 pp. https://www.nespmarine.edu.au/document/scoping-potential-species-ship-strike-risk-analysis*

Peel, D., Smith, J.N., and Erbe, C. (2017). *Report from Workshop on characterising underwater shipping noise in Australia.* Report to the National Environmental Science Programme, Marine Biodiversity Hub. *CSIRO. 14 pp.* *https://www.nespmarine.edu.au/document/report-workshop-characterising-underwater-shipping-noise-australia*

Peel, D., Smith, J., & Childerhouse, S. (2018). Vessel strike of whales in Australia: The challenges of analysis of historical incident data. *Frontiers in Marine Science*, ***5***, 69. https://www.frontiersin.org/articles/10.3389/fmars.2018.00069/full

Peel, D.,Patterson, T., Smith., J., Double, M., and How, J. (In prep). A Method for Satellite Tag Data Interpolation

Redfern J.V., Mckenna, M.F., Moore, T.J., Calambokidis, J., Deangelis, M.L., Becker, E.A., Barlow, J., Forney, K.A., Fiedler, P.C., Chivers, S.J. (2013) Assessing the risk of ships striking large whales in marine spatial planning. *Conservation Biology* **27**: 292-302. https://onlinelibrary.wiley.com/doi/abs/10.1111/cobi.12029

Rolland, R.M., Parks, S.E., Hunt, K.E., Castellote, M., Corkeron, P.J., Nowacek, D.P., et al. (2012). Evidence that ship noise increases stress in right whales. *Proc. R. Soc. Lond. B Biol. Sci*. **279**, 2363–2368. doi: 10.1098/rspb.2011.2429. http://rspb.royalsocietypublishing.org/content/279/1737/2363

Smith, J.N., Peel, D., Kelly, N., Childerhouse, S., Redfern, J. & Moore, T. (In prep). Quantifying the risk of ship strike to whales in a multiple use marine park: Great Barrier Reef. Submitted to Biological Conservation

Tregenza N, Aguilar N, Carrillo M, Delgado I, Diaz F, Brito A, Martin V. 2000. Potential impact of fast ferries on whale populations a simple model with examples from the Canary Islands. Proceedings of the 14th Annual Conference of the European Cetacean Society. Cork, Ireland; 195–197.

Van Der Hoop, J. M., Vanderlaan, A. S., & Taggart, C. T. (2012). Absolute probability estimates of lethal vessel strikes to North Atlantic right whales in Roseway Basin, Scotian Shelf. Ecological Applications, 22(7), 2021-2033. https://esajournals.onlinelibrary.wiley.com/doi/full/10.1890/11-1841.1

Vander Hoorn, S. (2016) *Prediction of risk exposure given changes in traffic and risk profiles, Technical Report prepared for the Australian Maritime Safety Authority*, Statistical Consulting Centre, The University of Melbourne, 8th February 2016

Vander Hoorn, S., & Knapp, S. (2015). A multi-layered risk exposure assessment approach for the shipping industry. Transportation Research Part A: Policy and Practice, 78, 21-33.

Vanderlaan ASM, Taggart CT (2006) Vessel collisions with whales: the probability of lethal injury based on vessel speed. Marine Mammal Science 23: 144-156.

Vanderlaan, A.S.M., Taggart, C.T., Serdynska, A.R., Kenney, R.D., Brown, M.W. (2008). Reducing the risk of lethal encounters: vessels and right whales in the Bay of Fundy and on the Scotian Shelf. Endangered Species Res. 4, 283–297.

APPENDIX A – DATA/MAP METADATA

Appendix Table 1 AIS maps metadata links

Name	Detail	Relevant figures	Download Link
Large vessels	≥80m of length	**Figure 6**	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!e11903ab-836c-4b67-aa41-b2fcf7f70ed2
Small vessels	<80m length	**Figure 7**	
Size classes	<10m length	**Figure 8**	
	10-25m length	**Figure 9**	
	25-50m length	**Figure 10**	
	50-100m length	**Figure 11**	
	100-200m length	**Figure 12**	
	>200m length	**Figure 13**	
Vessel types	Cargo	**Figure 15**	
	Fishing	**Figure 16**	
	Harbour (e.g., tugs, pilot vessels)	**Figure 17**	
	Military	**Figure 18**	
	Official	**Figure 19**	
	Passenger (e.g., ferries, cruise ships)	**Figure 20**	
	Recreational	**Figure 21**	
	Sailing vessels	**Figure 22**	
	Tanker	**Figure 23**	
	Working vessels (e.g., offshore supply vessels, dredgers)	**Figure 24**	
Fast vessels	Travelling >15kts speed	**Figure 25**	
Fast moving ferries	Passenger/ferry travelling >15kts speed	**Figure 26**	

Appendix Table 2 Data sets metadata/links

Name	Relevant figures or Section	Link/Metadata
Historical Australian whale incidents	**Section 10.1**	https://doi.org/10.25919/5be5086a6fda1
Distribution map for Western Australian Humpback whale Migration	**Figure 30 Figure 31**	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!11bc59db-1d78-438f-bb37-7adc7eea1d29

Appendix Table 3 Vessel strike risk maps

Type	Relevant figures	Link
West coast humpback risk	**Figure 32- Figure 35**	http://www.marlin.csiro.au/geonetwork/srv/eng/search#!40e7e293-e5e2-4d46-9611-c2db22182b24
GBR humpback risk	**Figure 46 - Figure 50**	
Southern Queensland humpback risk	**Figure 53 - Figure 56**	
Green Turtle risk	**Figure 82 Figure 83**	
Dugong risk	**Figure 79 Figure 80**	

APPENDIX B – SPECIES RANKING TABLE

	Species	Priority			Feasibility				
		Vessel strike Evidence	EPBC/IUCN	Priority	Species Distribution Information	Vessel size data needed	Feasibility	Suitability	Project Order
Cetaceans	Humpback whale	Strong	M	Med	3	Large	3	A	Phase 1
	Pygmy blue whale	Strong	H	High	4	Large	4	B	
	Antarctic blue whale	Strong	H	High	5	Large	5	C	
	Southern right whale	Strong	H	High	3	Large	3	A	Phase 1
	Dwarf minke whale	Strong	L	Low	4	Large	4	C	
	Antarctic minke whale	Strong	L	Low	5	Large	5	C	
	Fin whale	Strong	H	High	5	Large	5	C	
	Sei whale	Strong	H	High	5	Large	5	C	
	Bryde's whale	Strong	L	Low	5	Large	5	C	
	Pygmy right whale	Strong	L	Low	5	Large	5	C	
	Sperm whale	Strong	M	Med	4	Large	4	B	
	Pygmy sperm whale	Strong	L	Low	5	Large	5	C	
	Dwarf sperm whale	Strong	L	Low	5	Large	5	C	
	Pilot whale (long & short finned)	Strong	L	Low	5	Large	5	C	
	Killer whale	Medium	L	Low	4	Large	4	C	
	False killer whale	Medium	L	Low	5	Large	5	C	
	Pygmy killer whale	None	L	Low	5	Large	5	C	
	Omura's whale	Strong	L	Low	5	Large	5	C	
Dolphins	Australian snubfin dolphin	Strong	H	High	4	Small	4	B	Phase 3
	Aus. humpback dolphin	Strong	H	High	4	Small	4	B	Phase 3
	Common Bottlenose dolphin	Strong	L	Low	4	Small	4	C	
	Indo-Pacific Bottlenose dolphin	Strong	L	Low	4	Small	4	C	
	Risso's dolphin	Strong	L	Low	5	Small	5	C	
	Short beaked common dolphin	None	L	Low	5	Small	5	C	
	Dugong	Strong	L	Low	3	Small	3	B	Phase 2
Seals	Australian sea lion	None	M	Med	4	Small	4	C	
	New Zealand fur seal	None	L	Low	5	Small	5	C	
	Australian fur seal	None	L	Low	5	Small	5	C	
	Antarctic fur seal	None	M	Low	5	Small	5	C	
	Sub-Antarctic fur seal	None	M	Low	5	Small	5	C	
	Southern elephant seal	Medium	M	Low	4	Small	4	C	
Turtles	Green turtle	Strong	H	High	4	Small	4	B	Phase 3
	Loggerhead turtle	Strong	H	High	5	Small	5	C	
	Leatherback turtle	Strong	H	High	4	Small	4	B	
	Hawksbill turtle	Strong	H	High	5	Small	5	C	
	Olive Ridley turtle	Strong	M	Med	5	Small	5	C	
	Flatback turtle	Strong	H	High	5	Small	5	C	
	Whale shark	Strong	L	Low	4	?	4	C	
	Great white sharks	None	M	Low	5	?	5	C	
	Ocean sunfish	Strong	M	Med	5	Yacht	5	C	
	Little penguin	Strong	L	Low	4	Small	4	C	

APPENDIX C – AIS DATA PROCESSING

C1 Data validation

Summary tables were compiled listing each unique vessel (based on MMSI) and summarising the values in the available data for various information (e.g., length, beam, draught, type, class, name, IMO, etc.). By doing this, we could easily discern vessels with missing or multiple values

C2 Data filtering/cleaning

The supplied AIS data was filtered and pre-processed as per rules in the following tables.

Appendix Table 4 Initial AIS filtering

Filtering	Criteria	Comment
Speed	> 0.4 knots	The AIS data we have does not have navigational status which can be used to filter out vessels which are not underway (e.g., anchored). Since obviously stationary vessels are of no concern, we attempted to remove these with this criterion[28]
Valid MMSI only	201,000,000 ≤ MMSI ≤ 775,999,999	MMSI outside this range are invalid and produced by corrupt data.

[28] 0.4 kts was used to remove stationary vessels that drift. This was not completely successful, but since our vessel strike risk metrics all involve distance traversed and/or speed this should not cause any considerable bias.

Appendix Table 5: AIS line creation validity criteria

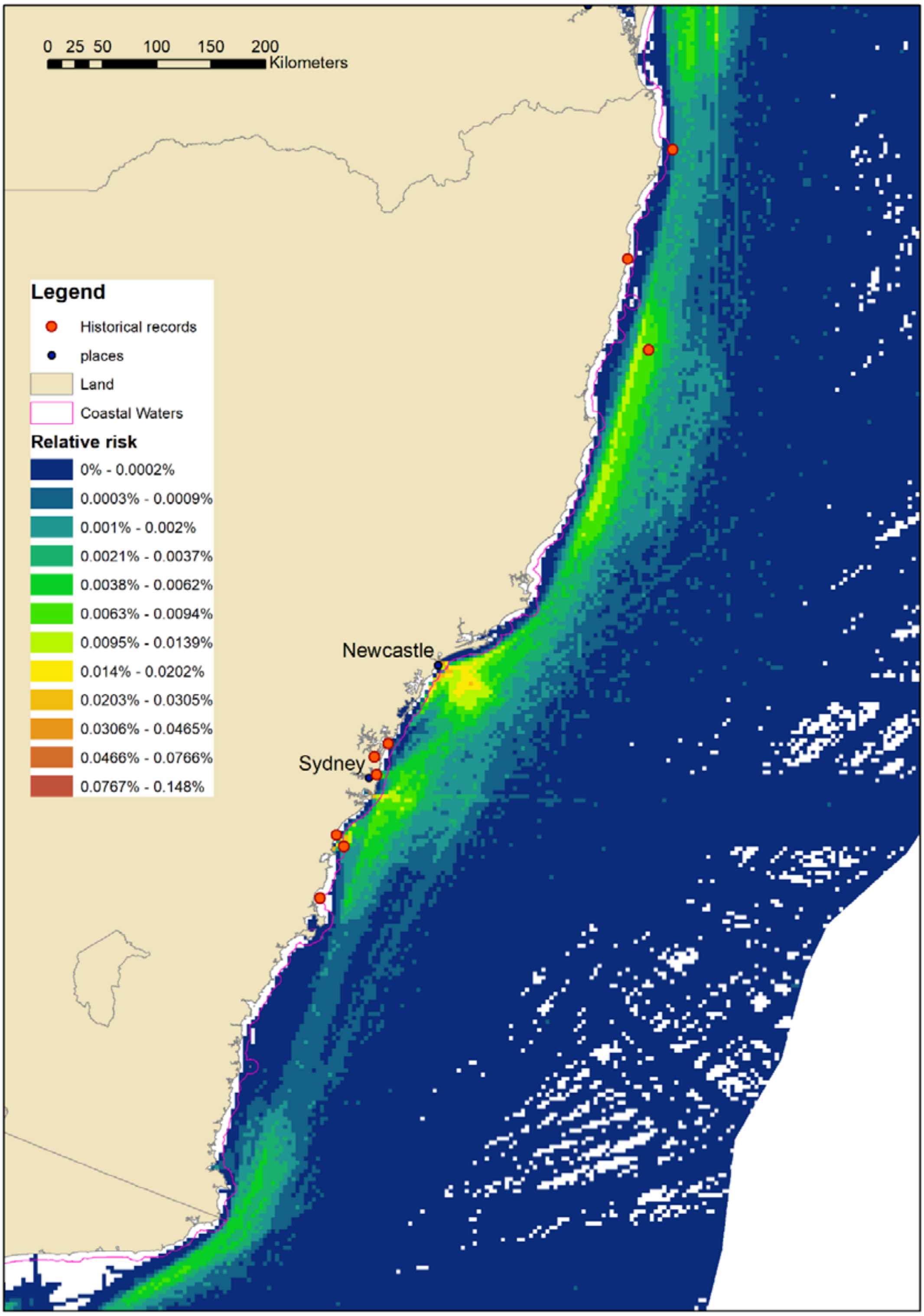
Filtering	Criteria	Comment
Max polling interval time (∆t)	If ∆t ≤ 30 mins then keep	Although the data is sampled at a poll every 5 mins, due to technical issues on some occasions polling is less frequent. We added this limit as beyond that the path/track of the vessel between the poll locations is highly uncertain
Longer polling time (∆t) but straight travel ∆COG	If 30 mins ≤ ∆t ≤ 60 mins **and** ∆COG ≤ 5° Then keep	If the polling interval ∆t is longer but the vessel seems to be travelling reasonably straight (based on the change in course over ground ∆COG), we are still reasonably confident we can interpolate where the vessel was between polls
Longer polling time (∆t) but not straight travel ∆COG	If 30 mins ≤ ∆t ≤ 60 mins **and** ∆COG > 5° Then remove	
Long polling time	If ∆t > 60 remove	If the polling interval ∆t is too great, we cannot be certain the path the vessel took and so we delete the transect (the code has the option to leave the start and end points, in the data as they are certain locations, we did not use this option for our analysis)
Backwards timetravel and zero length lines	Remove any ∆t≤0 or line length = 0	This should not occur but if there is a negative change in time obviously something is wrong and this data is ignored
Ship tracks with apparent positional errors	Distance traversed equates to travel that equates to ≥ 60 knots	Occasionally due to corrupt data, bad GPS fix, or a mix up in reported MMSI from another vessel, vessels can jump at impossible speeds. These are removed.
Land	Leave in the data	Due to GPS errors or corrupt data, a very small number of locations correspond to land. Since our grid data used later is for 1 km^2 cells containing ocean, any obvious land points will be filtered out automatically at that stage.

APPENDIX D – STATE FOCUSED RESULTS

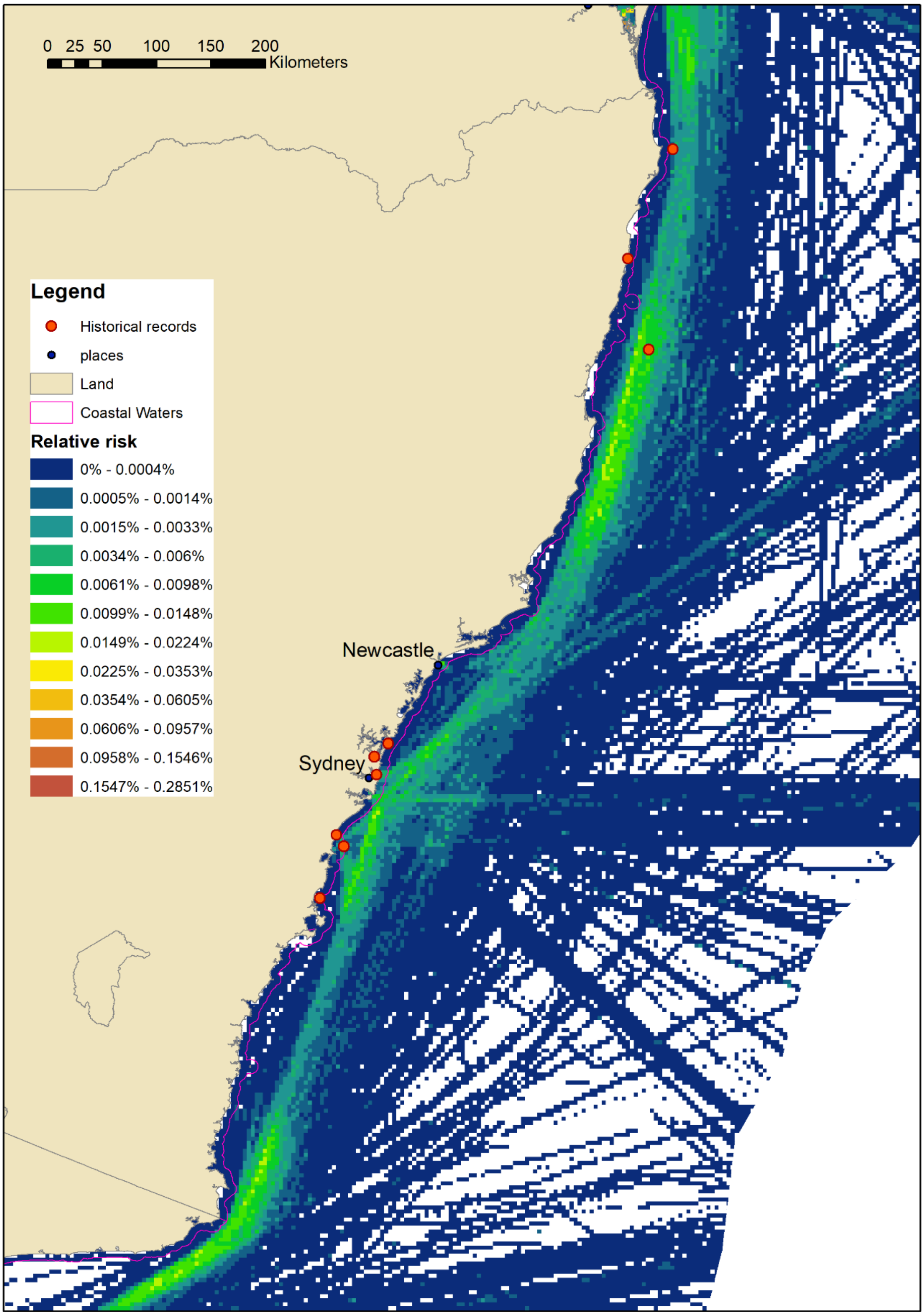
Appendix D1 – New South Whales

Appendix Table 6 Relevant map/data for NSW in this report

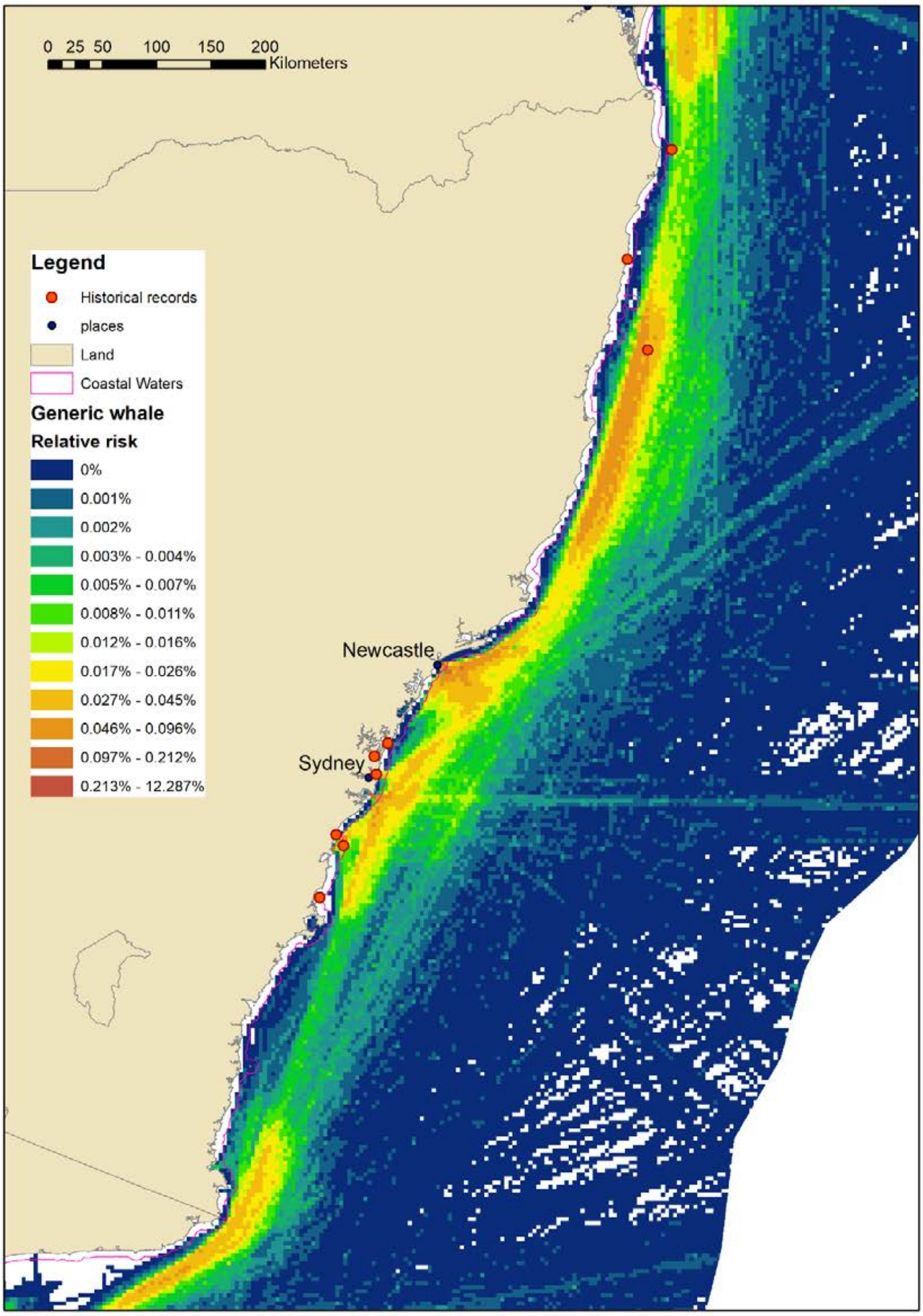
Species/Dataset	Relevant Figures
East coast Humpback	Figure 57; Figure 60; Figure 61;
Southern right whale	Figure 68
Sperm whale	Figure 73
Green Turtle	Figure 82; Figure 83
Generic species and large(>80m) AIS equipped vessel	Appendix Figure 1
Generic species and fast moving (>15kts) AIS equipped vessel	Appendix Figure 2
Generic whale and large(>80m) AIS equipped vessel	Appendix Figure 3



Appendix Figure 1 Relative risk of a collision with a generic species (assuming uniform animal density) and large (>80m length) AIS equipped vessels for NSW



Appendix Figure 2 Relative risk of a collision with a generic species (assuming uniform animal density) and fast (>15kts) moving AIS equipped vessels for NSW

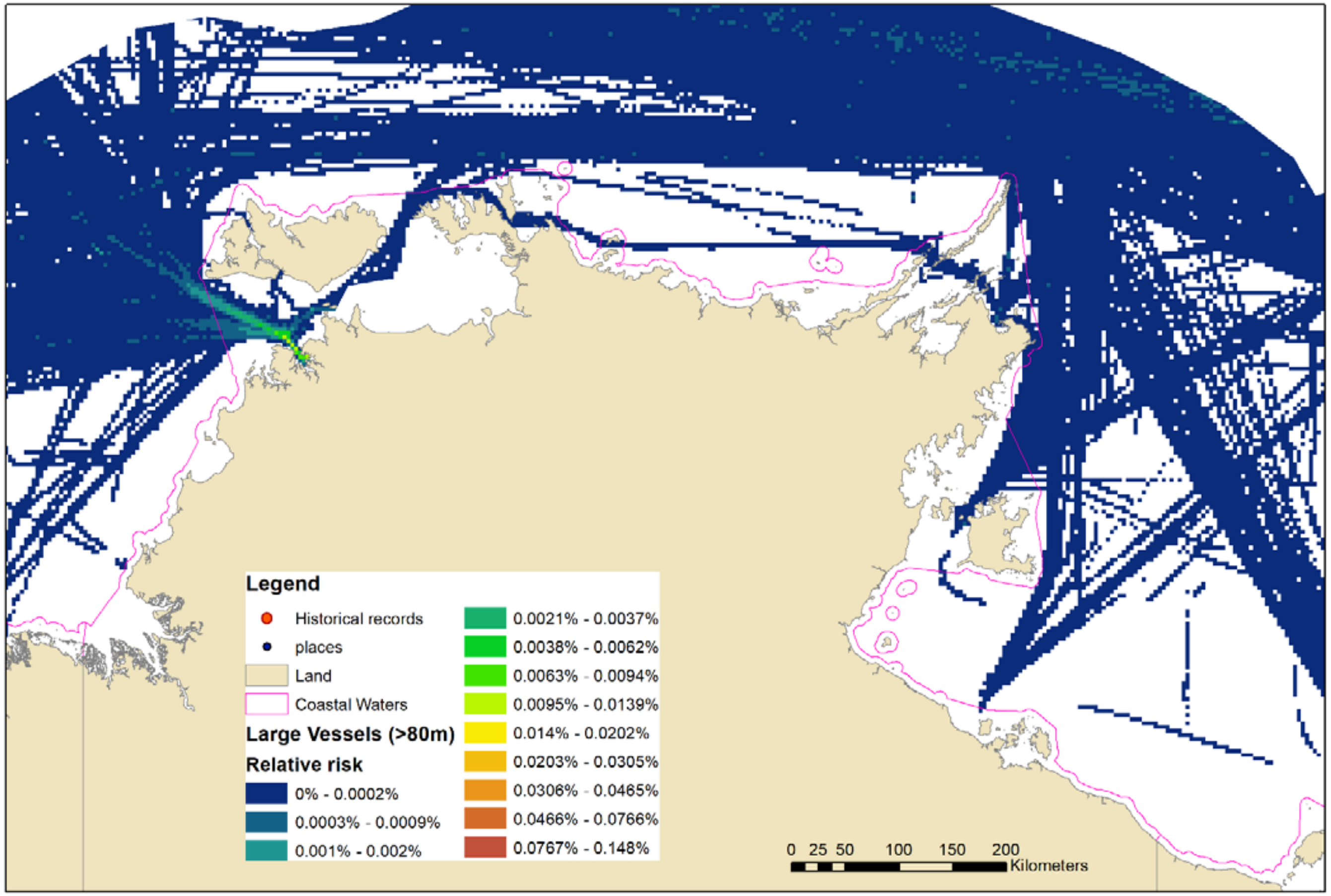


Appendix Figure 3 Generic relative risk of a fatal collision between a generic whale species in NSW (assuming uniform whale density) and large (>80m length) AIS equipped vessels

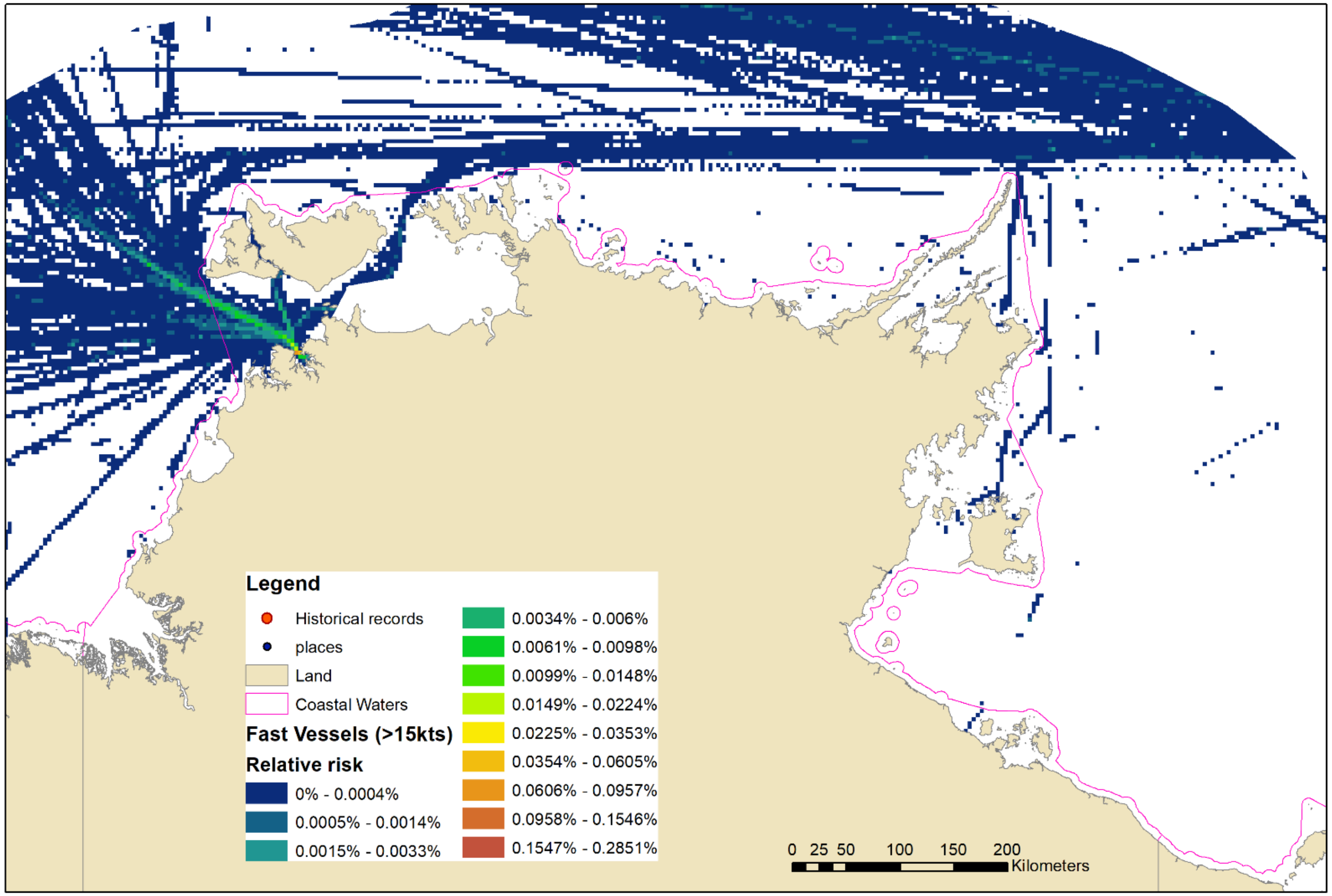
Appendix D2 – Northern Territory

Appendix Table 7 Relevant map/data for the Northern Territory in this report

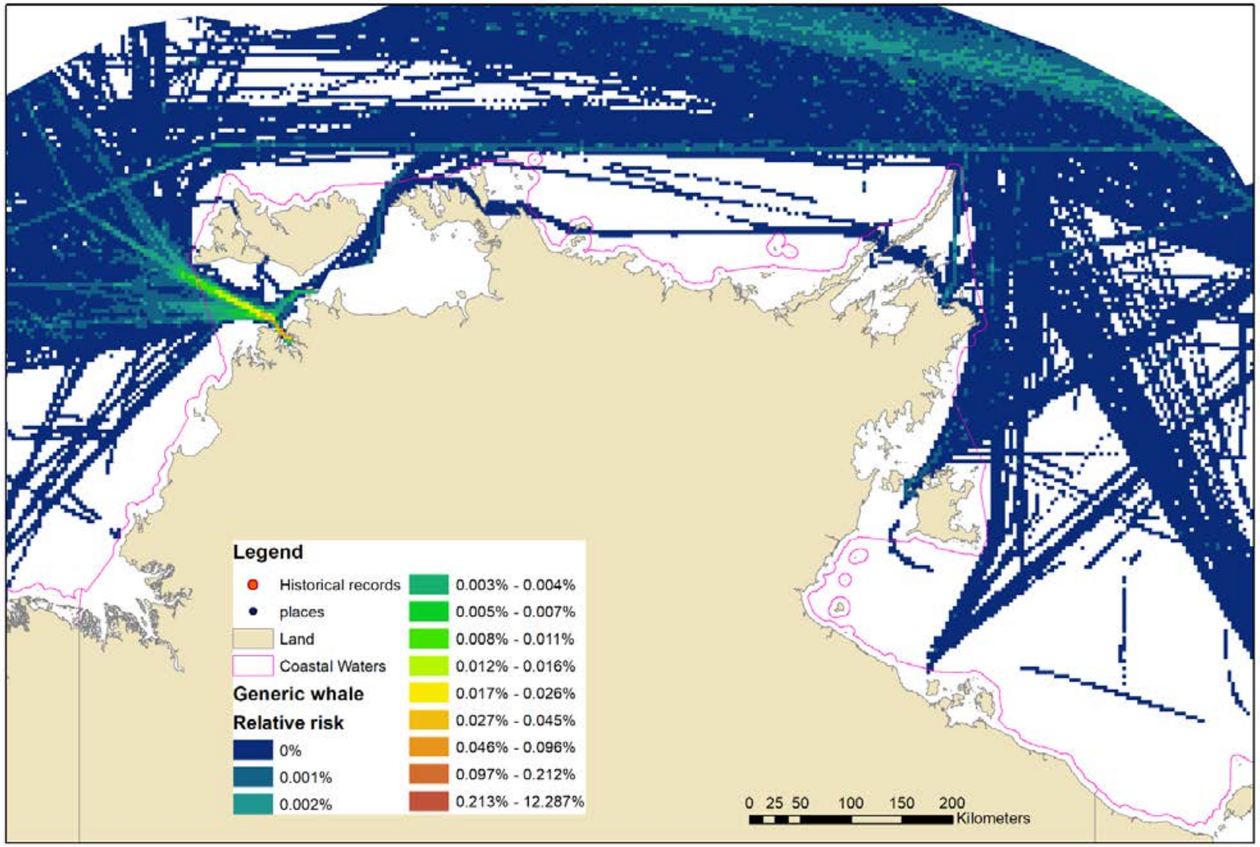
Species/Dataset	Relevant Figures
Sperm whale	Figure 73
Dugong	N/A
Green Turtle	Figure 82
Generic species and large(>80m) AIS equipped vessel	Appendix Figure 4
Generic species and fast moving (>15kts) AIS equipped vessel	Appendix Figure 5
Generic whale and large(>80m) AIS equipped vessel	Appendix Figure 6



Appendix Figure 4 Relative risk of a collision with a generic species (assuming uniform animal density) and large (>80m length) AIS equipped vessels for NT



Appendix Figure 5 Relative risk of a collision with a generic species (assuming uniform animal density) and fast (>15kts) moving AIS equipped vessels for NT

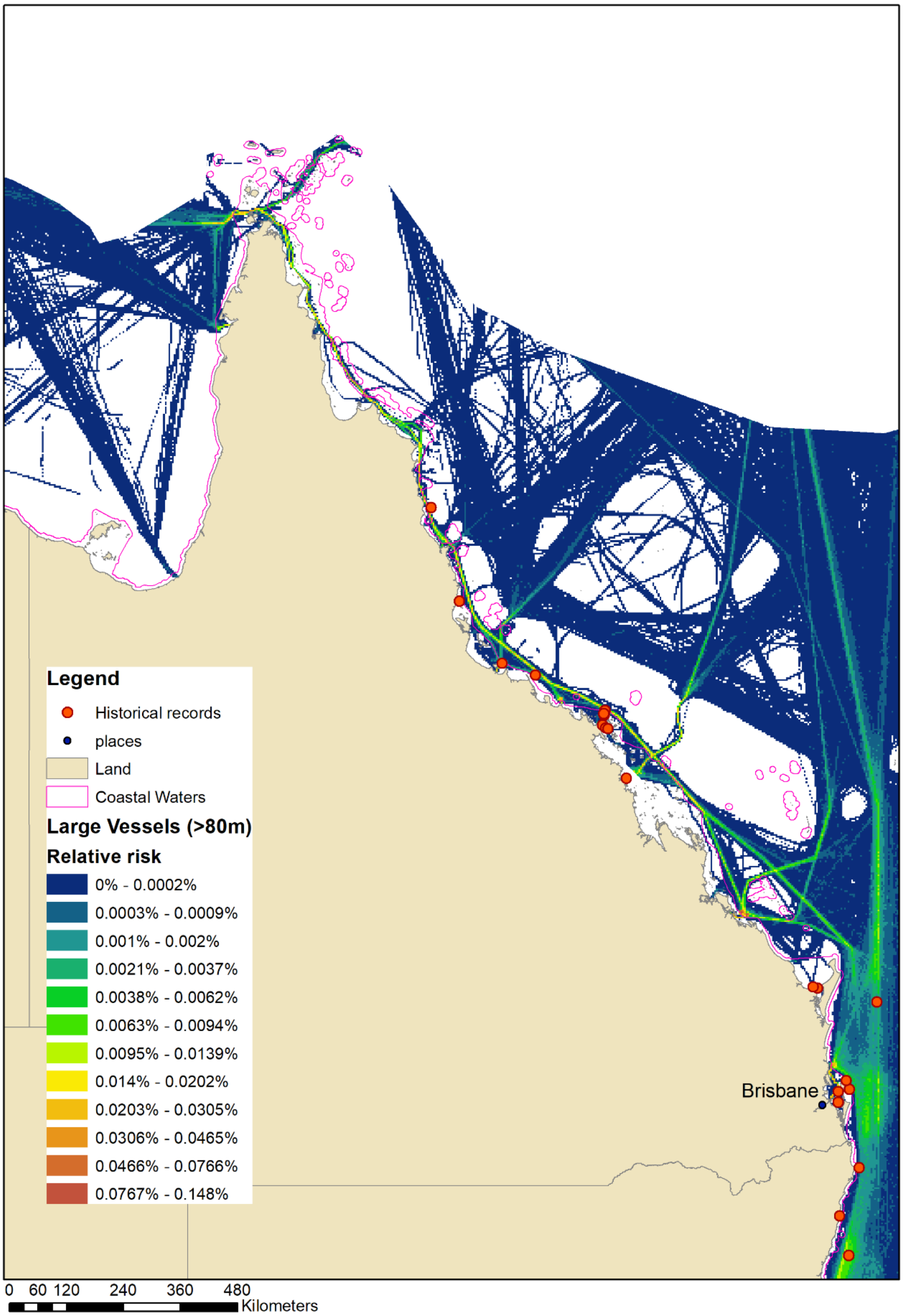


Appendix Figure 6 Generic relative risk of a fatal collision between a generic whale species in NT (assuming uniform whale density) and large (>80m length) AIS equipped vessels

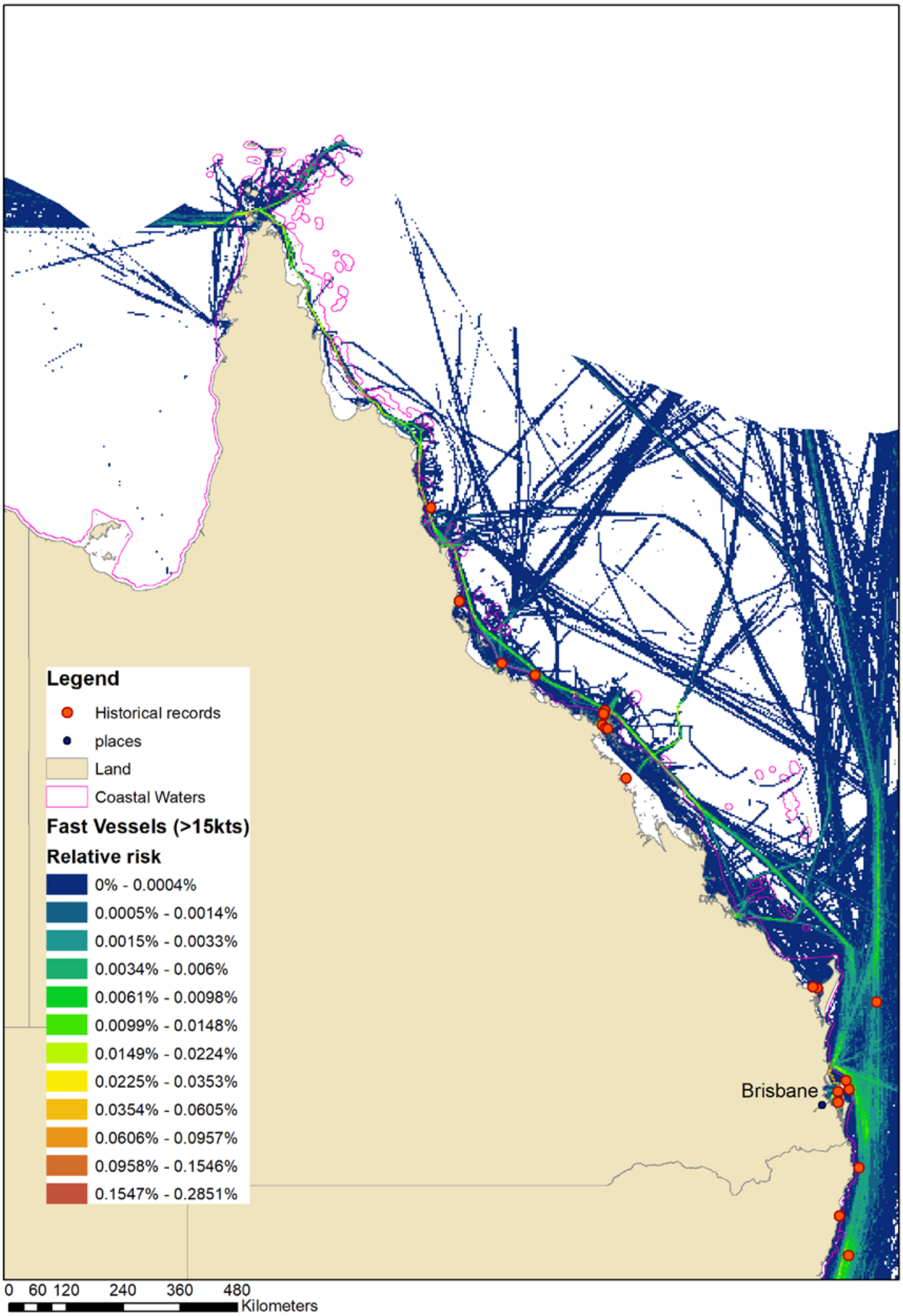
Appendix D3 – Queensland

Appendix Table 8 Relevant map/data for Queensland in this report

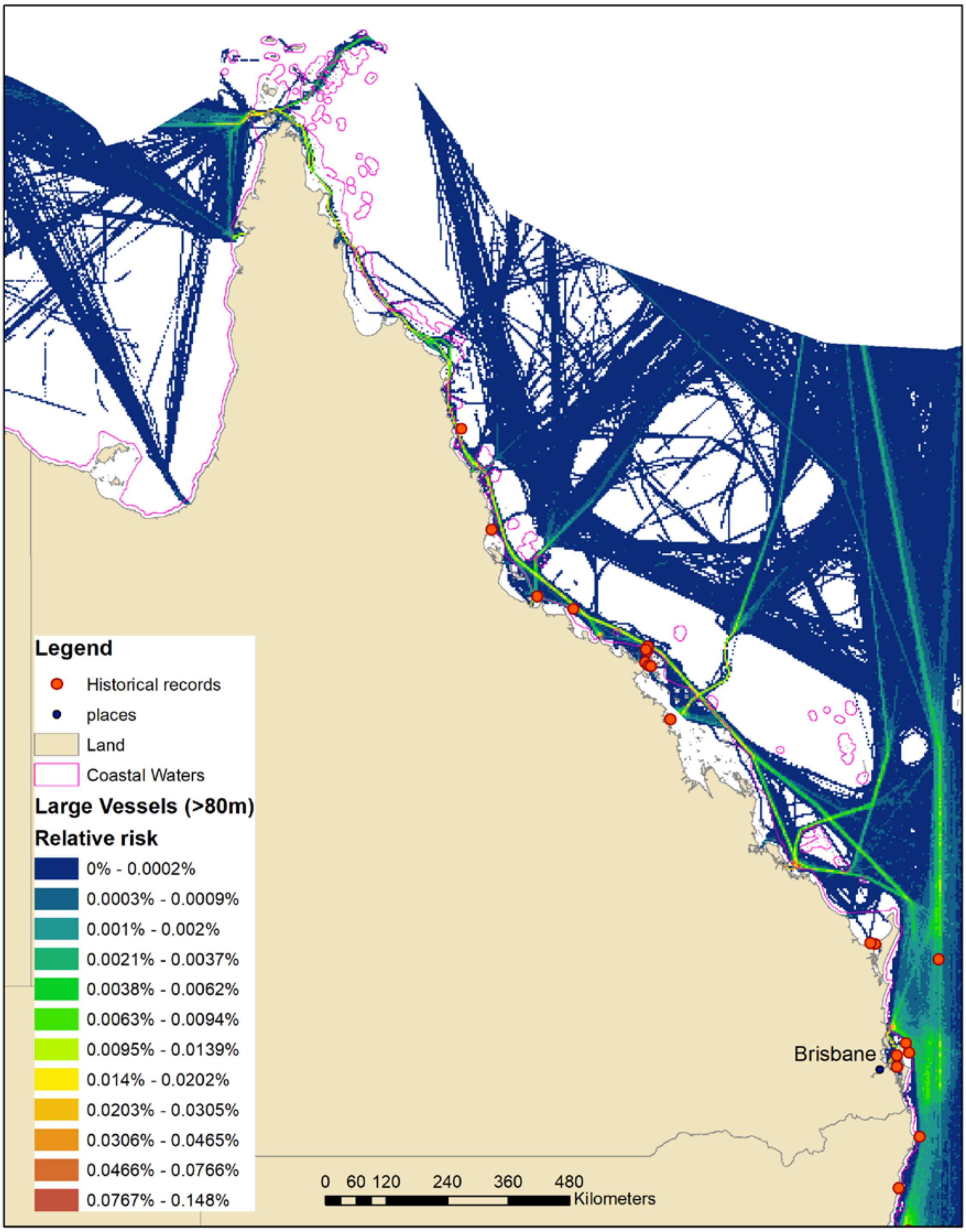
Species/Dataset	Relevant Figures
East coast Humpback	Figure 46 - Figure 61
Southern right whale	Figure 68
Sperm whale	Figure 73
Dugong	Figure 79; Figure 80
Green Turtle	Figure 81 - Figure 83
Generic species and large(>80m) AIS equipped vessel	Appendix Figure 7
Generic species and fast moving (>15kts) AIS equipped vessel	Appendix Figure 5; Appendix Figure 8
Generic whale and large(>80m) AIS equipped vessel	Appendix Figure 9



Appendix Figure 7 Relative risk of a collision with a generic species (assuming uniform animal density) and large (>80m length) AIS equipped vessels for QLD



Appendix Figure 8 Relative risk of a collision with a generic species (assuming uniform animal density) and fast (>15kts) moving AIS equipped vessels for QLD

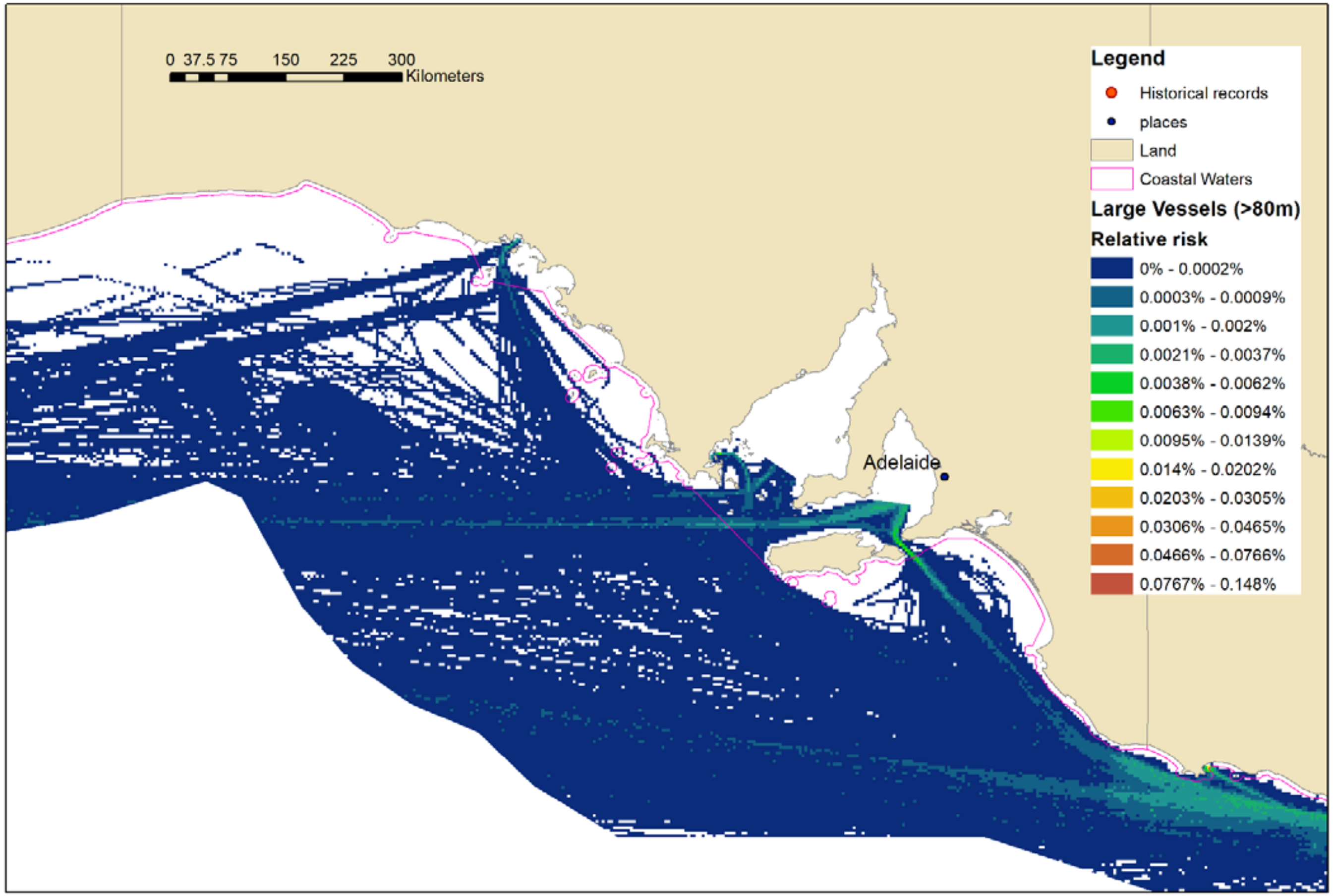


Appendix Figure 9 Generic relative risk of a fatal collision between a generic whale species in QLD (assuming uniform whale density) and large (>80m length) AIS equipped vessels

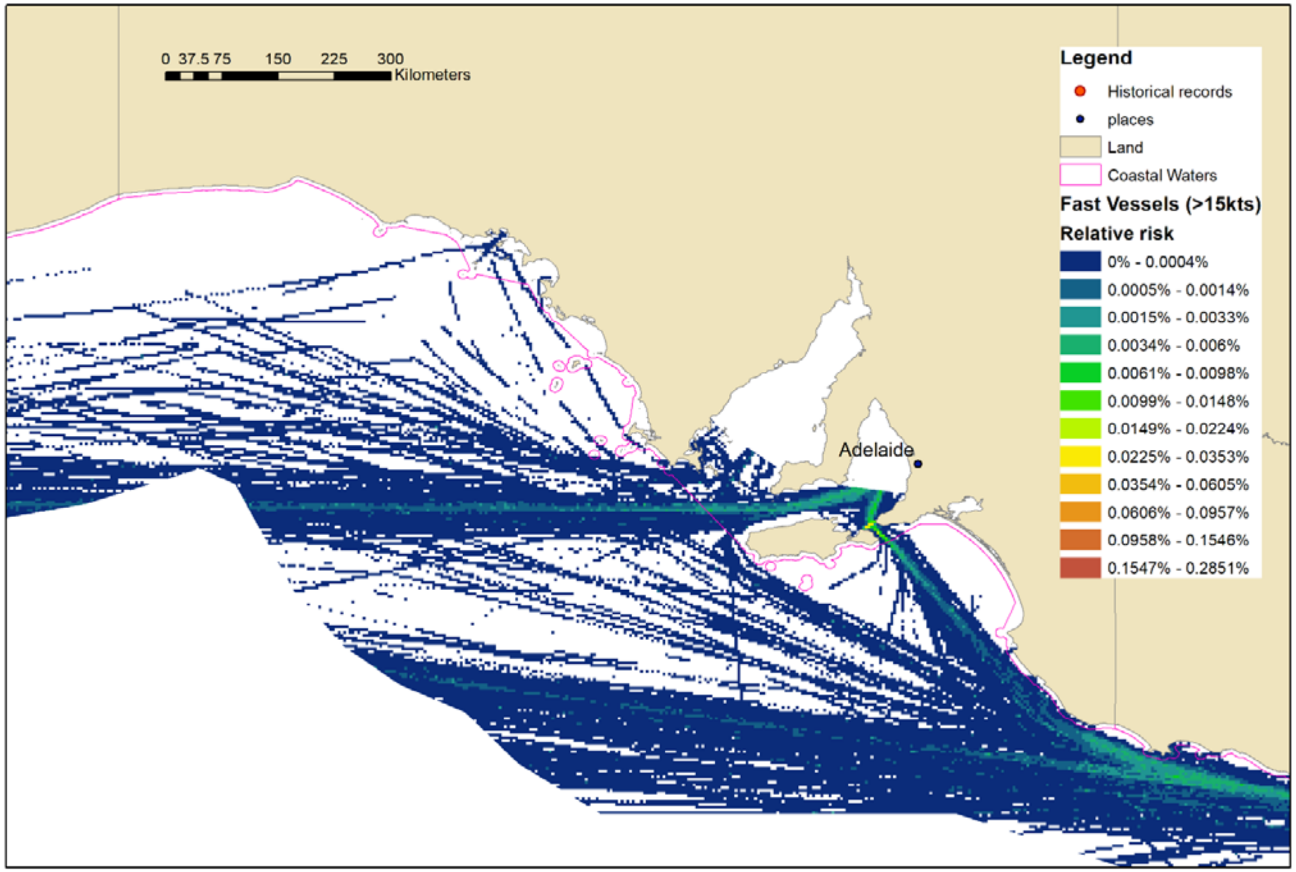
Appendix D4 – South Australia

Appendix Table 9 Relevant map/data for South Australia in this report

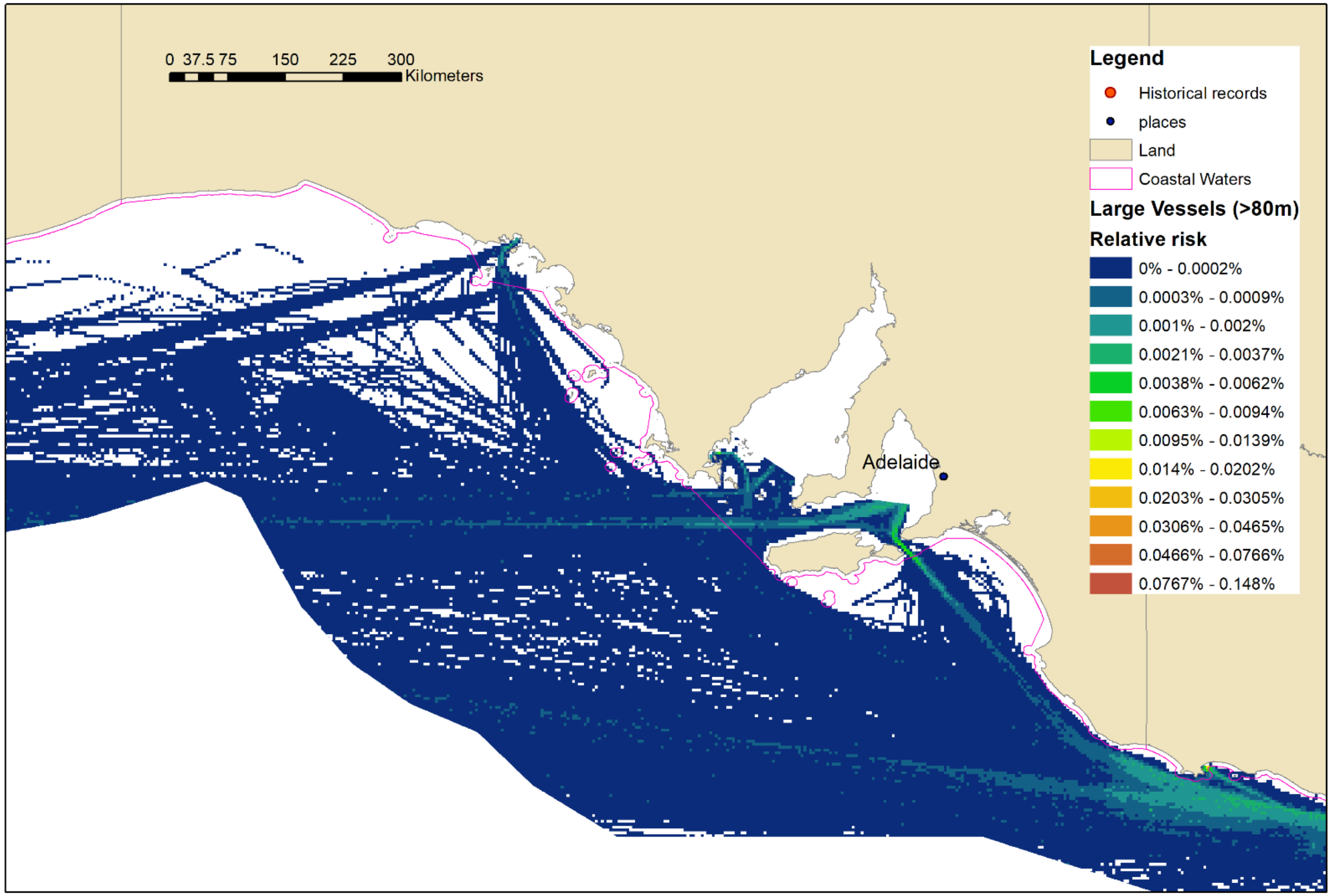
Species/Dataset	Relevant Figures
Southern right whale	Figure 62 - Figure 71
Sperm whale	Figure 73 - Figure 78
Generic species and large(>80m) AIS equipped vessel	Appendix Figure 10
Generic species and fast moving (>15kts) AIS equipped vessel	Appendix Figure 11
Generic whale and large(>80m) AIS equipped vessel	Appendix Figure 12



Appendix Figure 10 Relative risk of a collision with a generic species (assuming uniform animal density) and large (>80m length) AIS equipped vessels for SA



Appendix Figure 11 Relative risk of a collision with a generic species (assuming uniform animal density) and fast (>15kts) moving AIS equipped vessels for SA

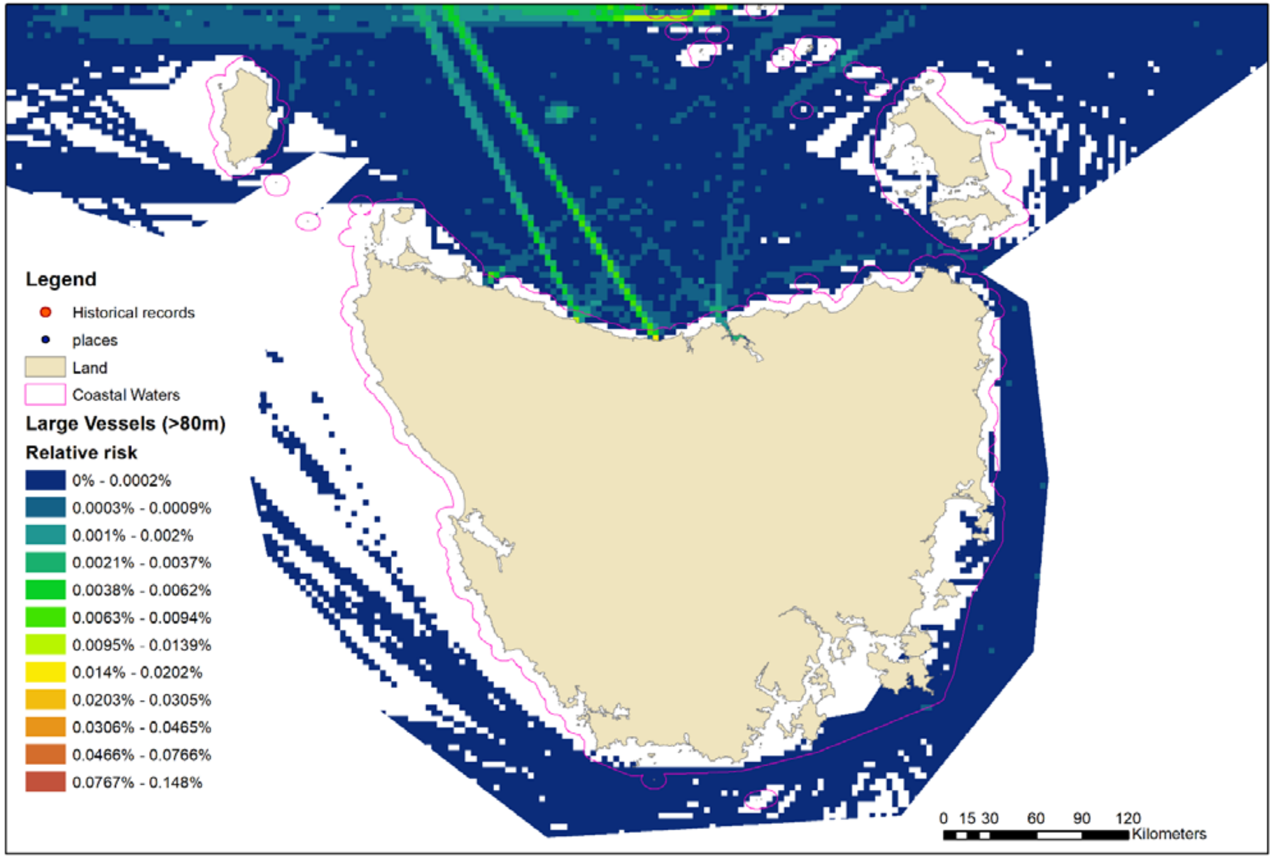


Appendix Figure 12 Generic relative risk of a fatal collision between a generic whale species in SA (assuming uniform whale density) and large (>80m length) AIS equipped vessels

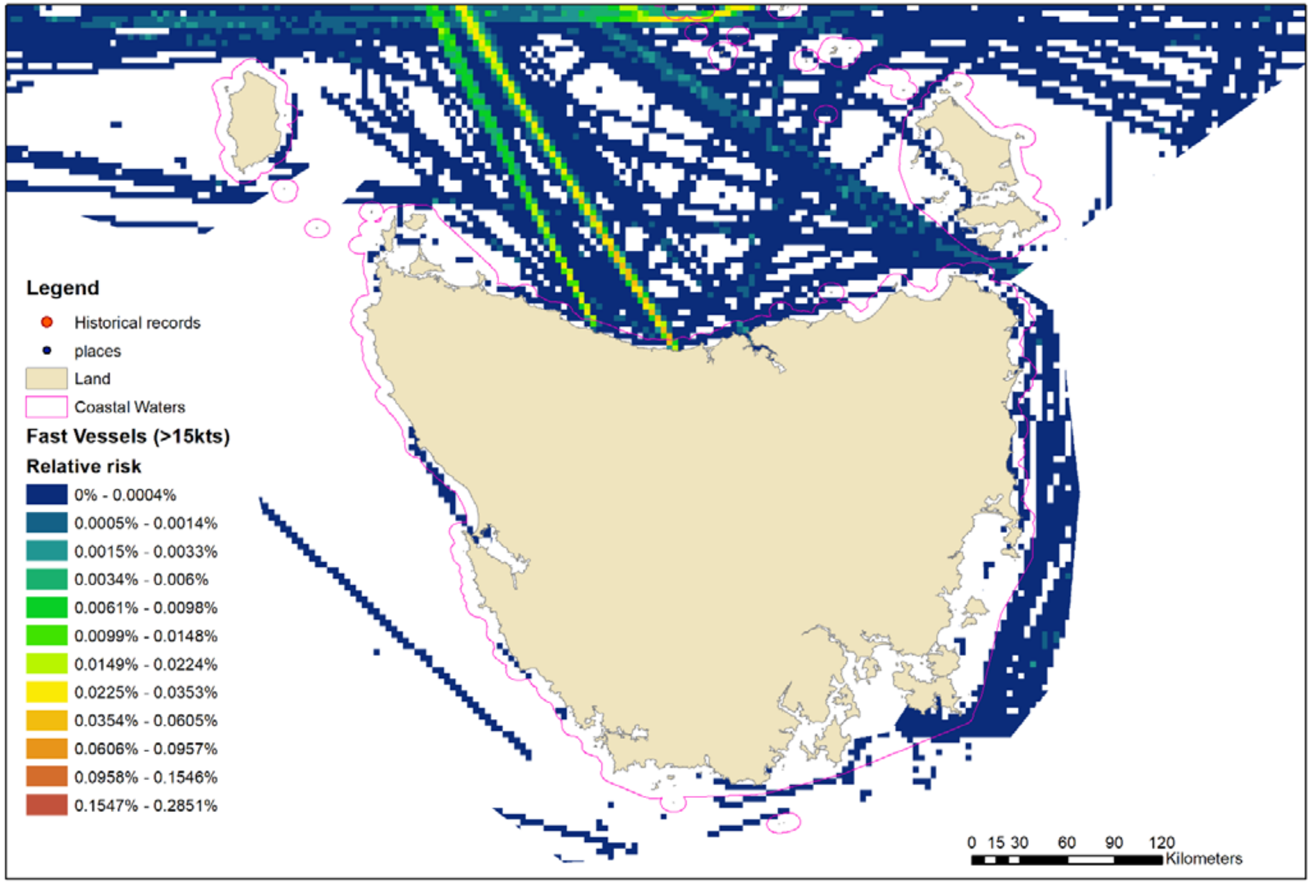
Appendix D5 – Tasmania

Appendix Table 10 Relevant map/data for Tasmania in this report

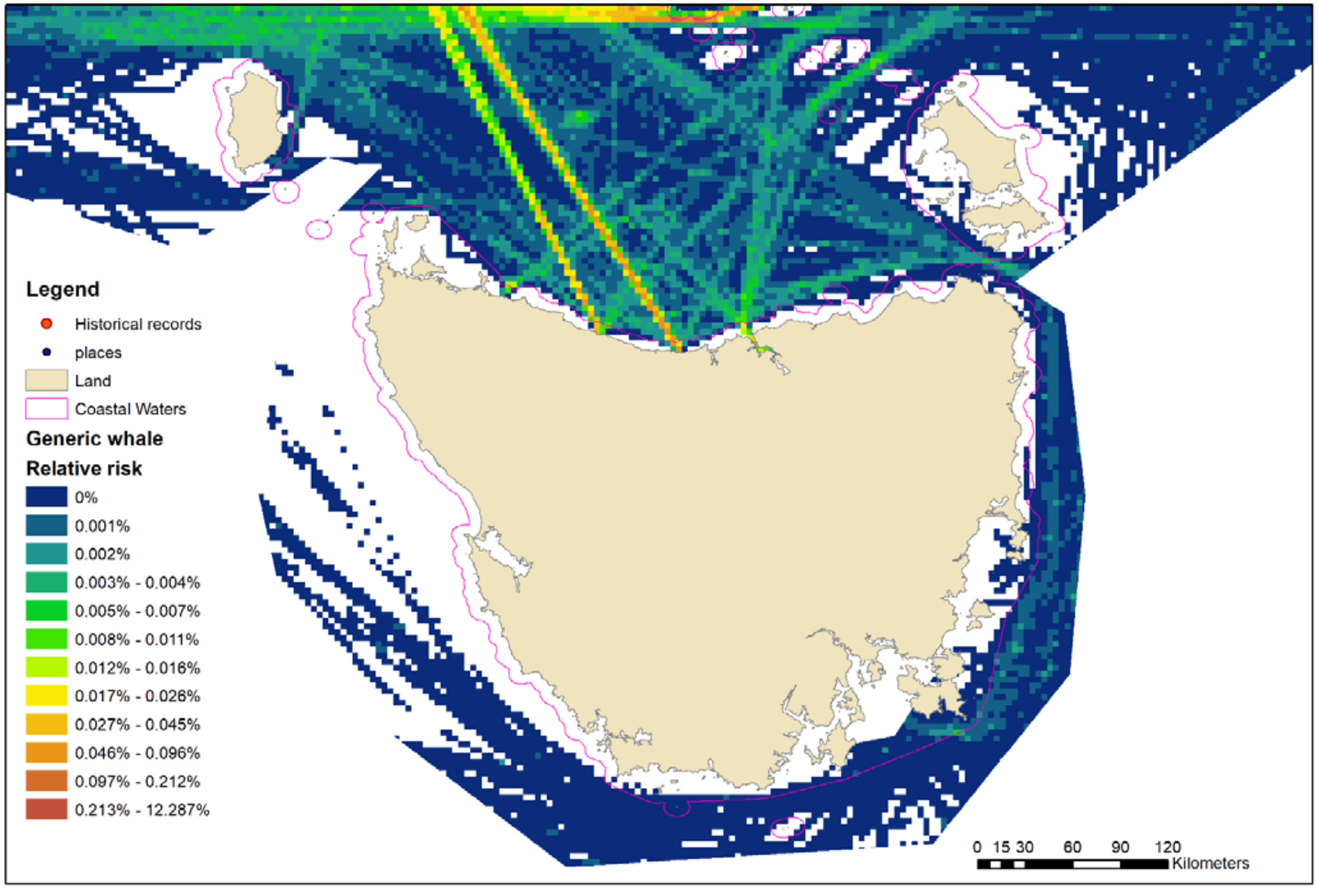
Species/Dataset	Relevant Figures
East coast Humpback	
Southern right whale	Figure 68
Sperm whale	**Figure 60**
Generic species and large(>80m) AIS equipped vessel	Appendix Figure 13
Generic species and fast moving (>15kts) AIS equipped vessel	Appendix Figure 14
Generic whale and large(>80m) AIS equipped vessel	Appendix Figure 15



Appendix Figure 13 Relative risk of a collision with a generic species (assuming uniform animal density) and large (>80m length) AIS equipped vessels for TAS



Appendix Figure 14 Relative risk of a collision with a generic species (assuming uniform animal density) and fast (>15kts) moving AIS equipped vessels for TAS

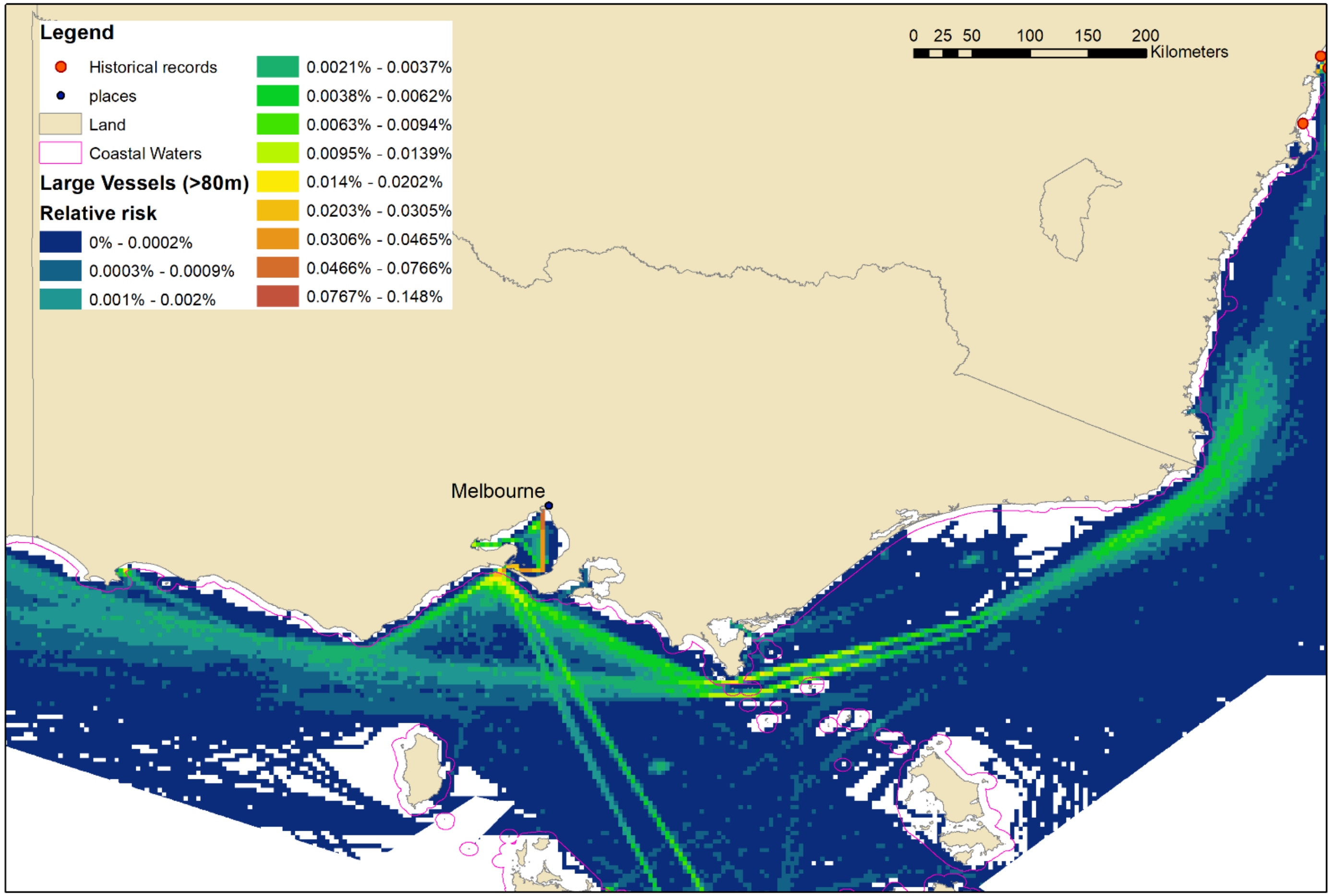


Appendix Figure 15 Generic relative risk of a fatal collision between a generic whale species in TAS (assuming uniform whale density) and large (>80m length) AIS equipped vessels

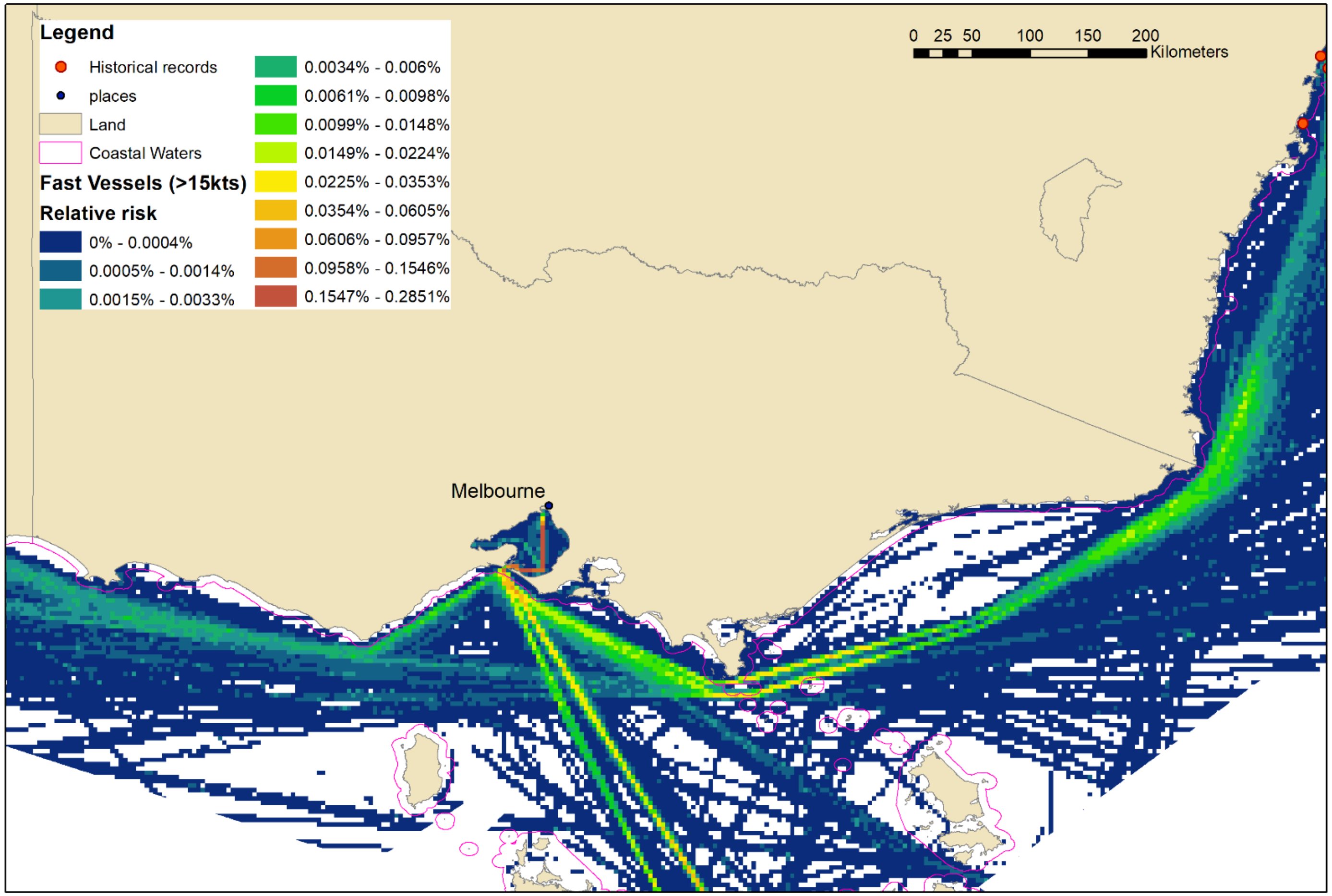
Appendix D6 – Victoria

Appendix Table 11 Relevant map/data for Victoria in this report

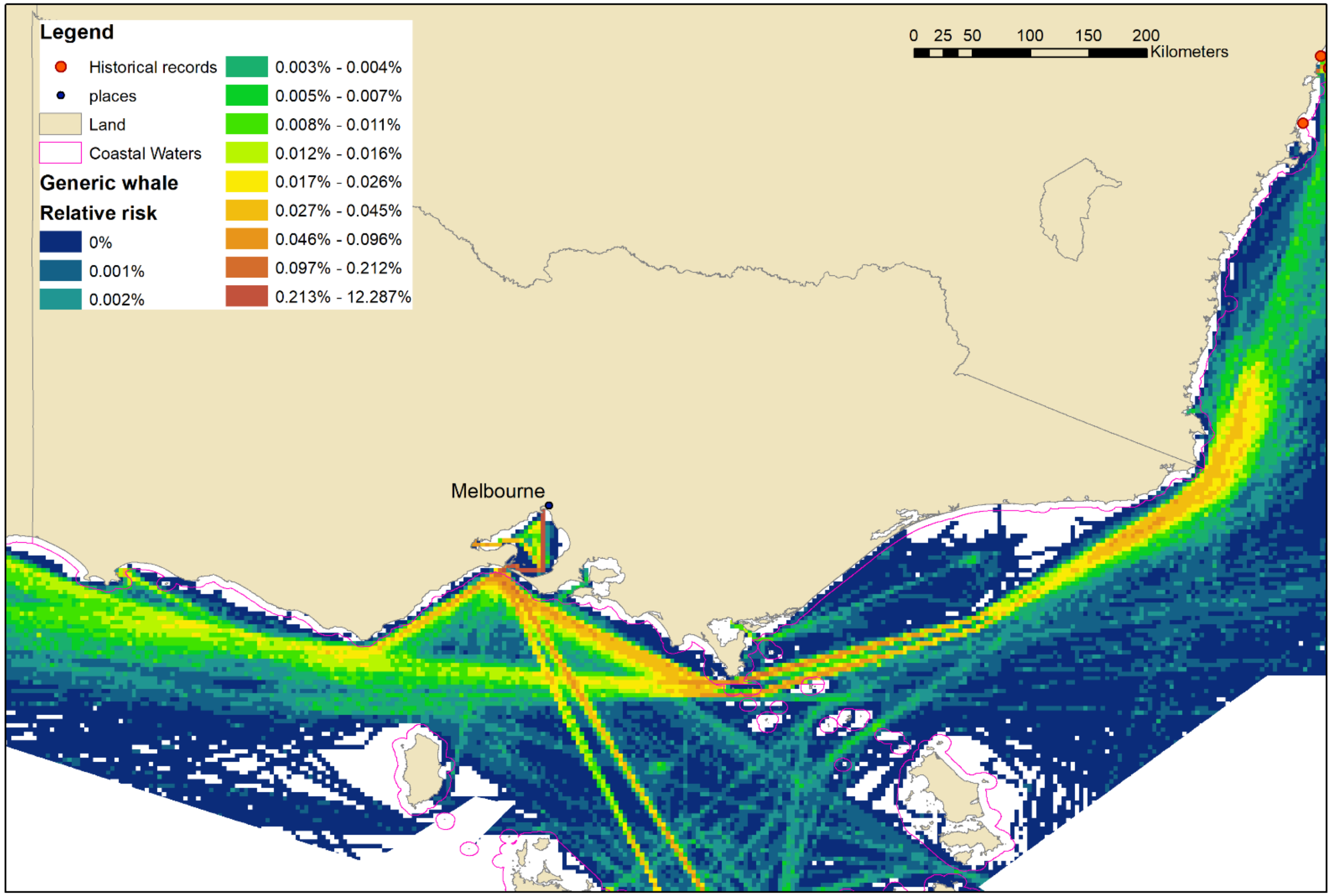
Species/Dataset	Relevant Figures
Southern right whale	Figure 62 - Figure 71
Sperm whale	Figure 73 - Figure 78
Green Turtle	
Generic species and large(>80m) AIS equipped vessel	Appendix Figure 16
Generic species and fast moving (>15kts) AIS equipped vessel	Appendix Figure 17
Generic whale and large(>80m) AIS equipped vessel	Appendix Figure 18



Appendix Figure 16 Relative risk of a collision with a generic species (assuming uniform animal density) and large (>80m length) AIS equipped vessels for VIC



Appendix Figure 17 Relative risk of a collision with a generic species (assuming uniform animal density) and fast (>15kts) moving AIS equipped vessels for VIC

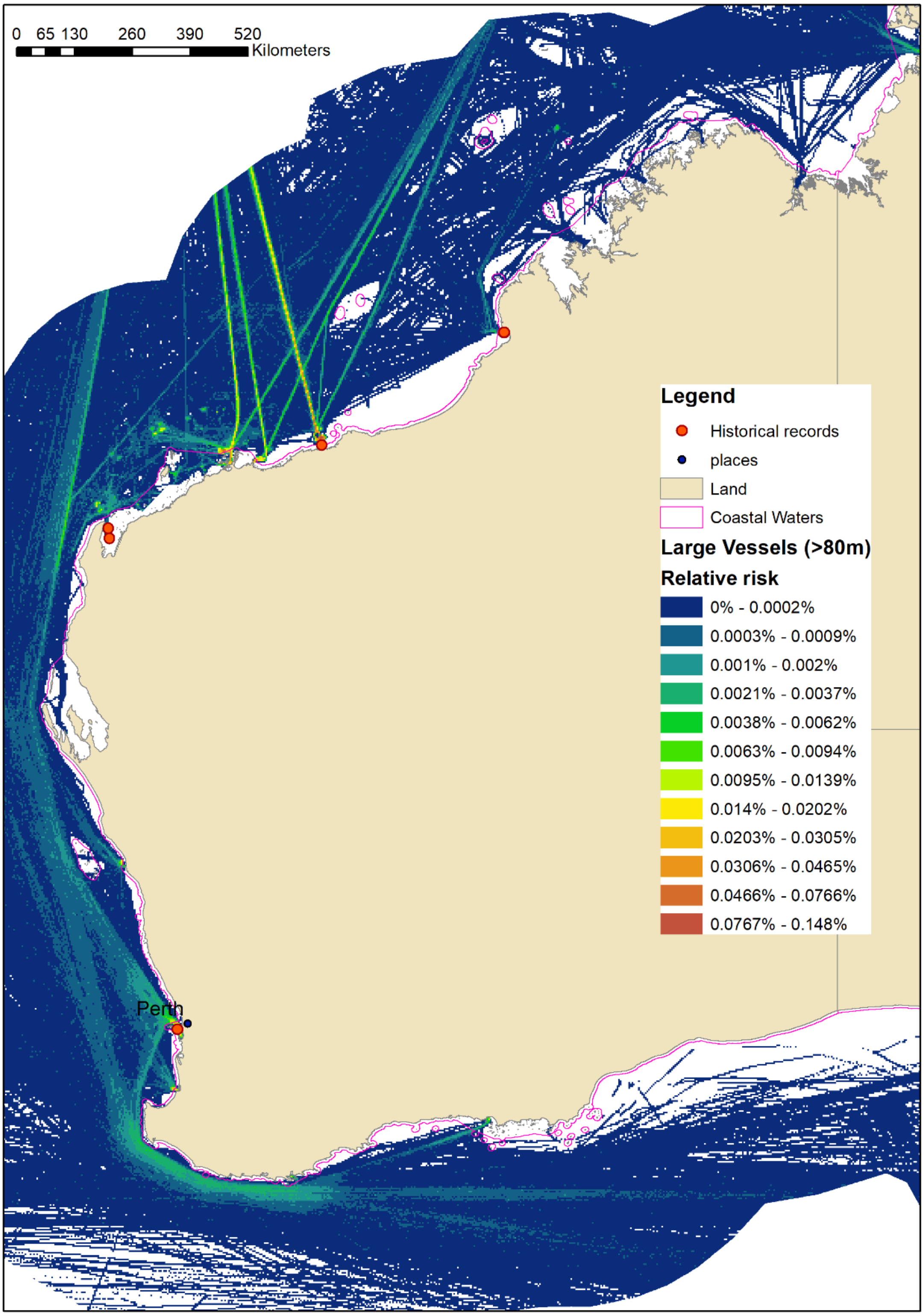


Appendix Figure 18 Generic relative risk of a fatal collision between a generic whale species in VIC (assuming uniform whale density) and large (>80m length) AIS equipped vessels

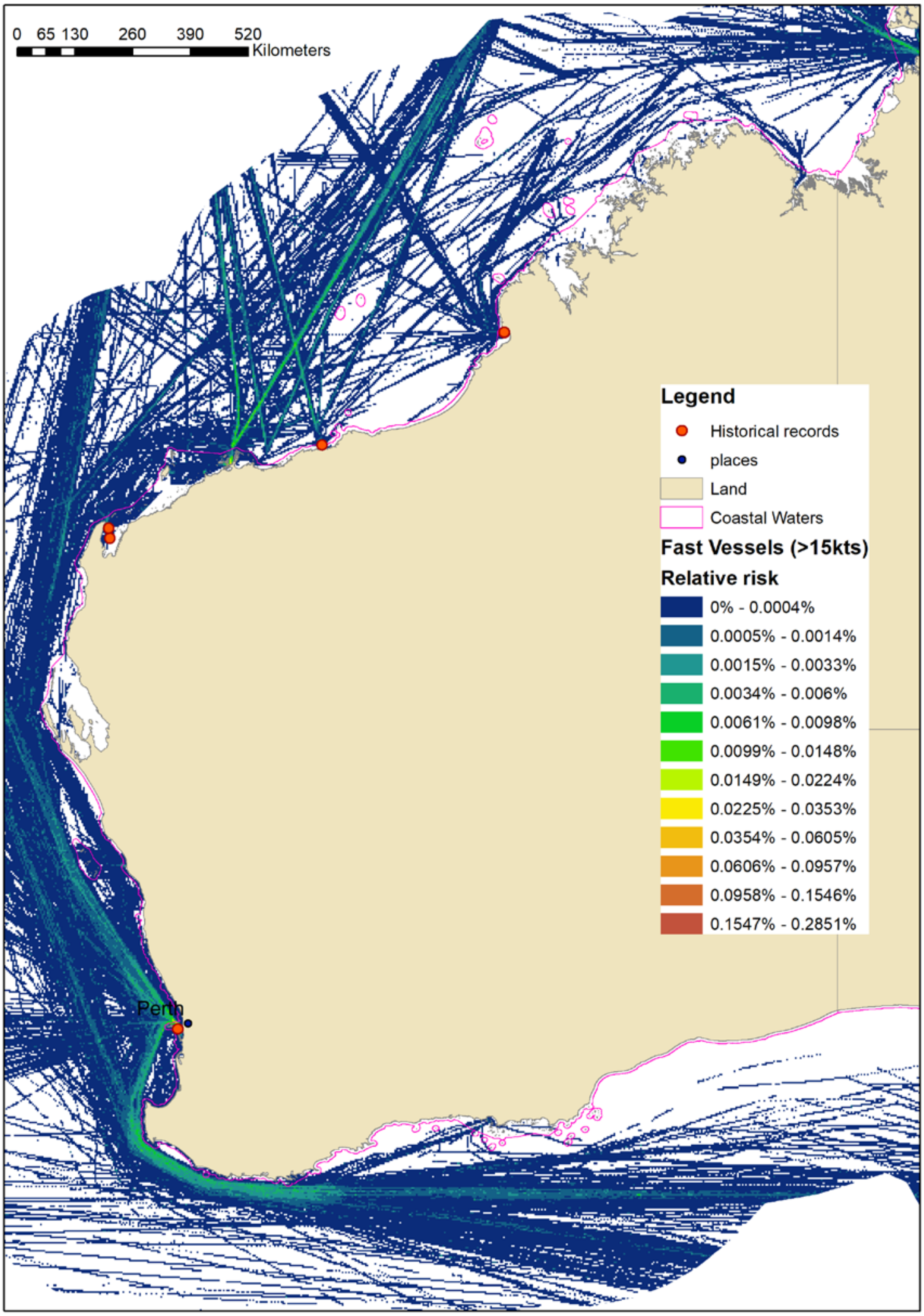
Appendix D7 – Western Australia

Appendix Table 12 Relevant map/data for Western Australia in this report

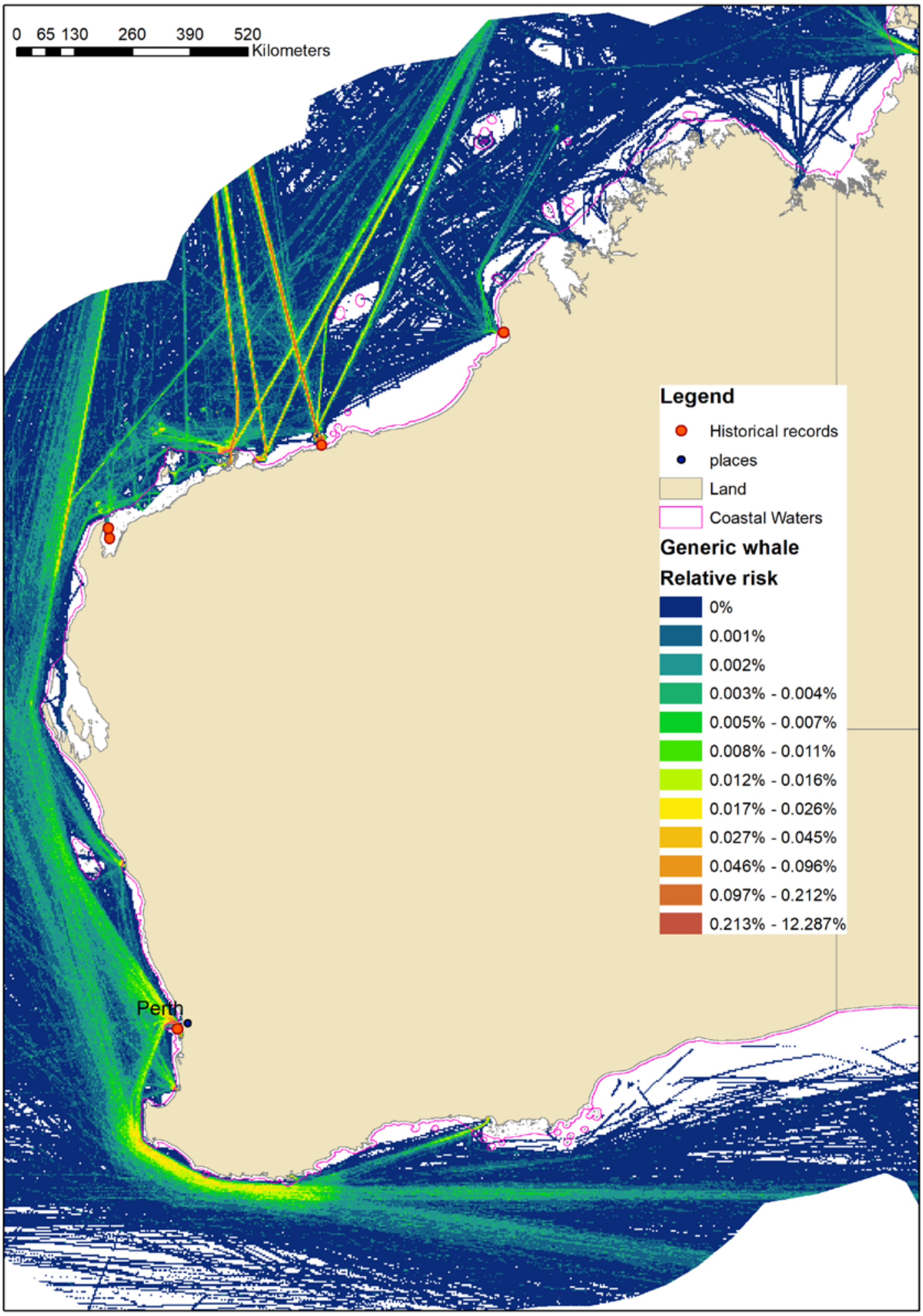
Species/Dataset	Relevant Figures
West coast Humpback	Figure 30 - Figure 40
Southern right whale	Figure 62 - Figure 71
Sperm whale	Figure 73 - Figure 78
Dugongs	
Green Turtle	Figure 81 - Figure 83
Generic species and large(>80m) AIS equipped vessel	Appendix Figure 19
Generic species and fast moving (>15kts) AIS equipped vessel	Appendix Figure 20
Generic whale and large(>80m) AIS equipped vessel	Appendix Figure 21



Appendix Figure 19 Relative risk of a collision with a generic species (assuming uniform animal density) and large (>80m length) AIS equipped vessels for WA



Appendix Figure 20 Relative risk of a collision with a generic species (assuming uniform animal density) and fast (>15kts) moving AIS equipped vessels for WA



Appendix Figure 21 Generic relative risk of a fatal collision between a generic whale species in WA (assuming uniform whale density) and large (>80m length) AIS equipped vessels

APPENDIX E – SOURCES OF UNCERTAINTY IN VESSEL STRIKE RISK CALCULATIONS

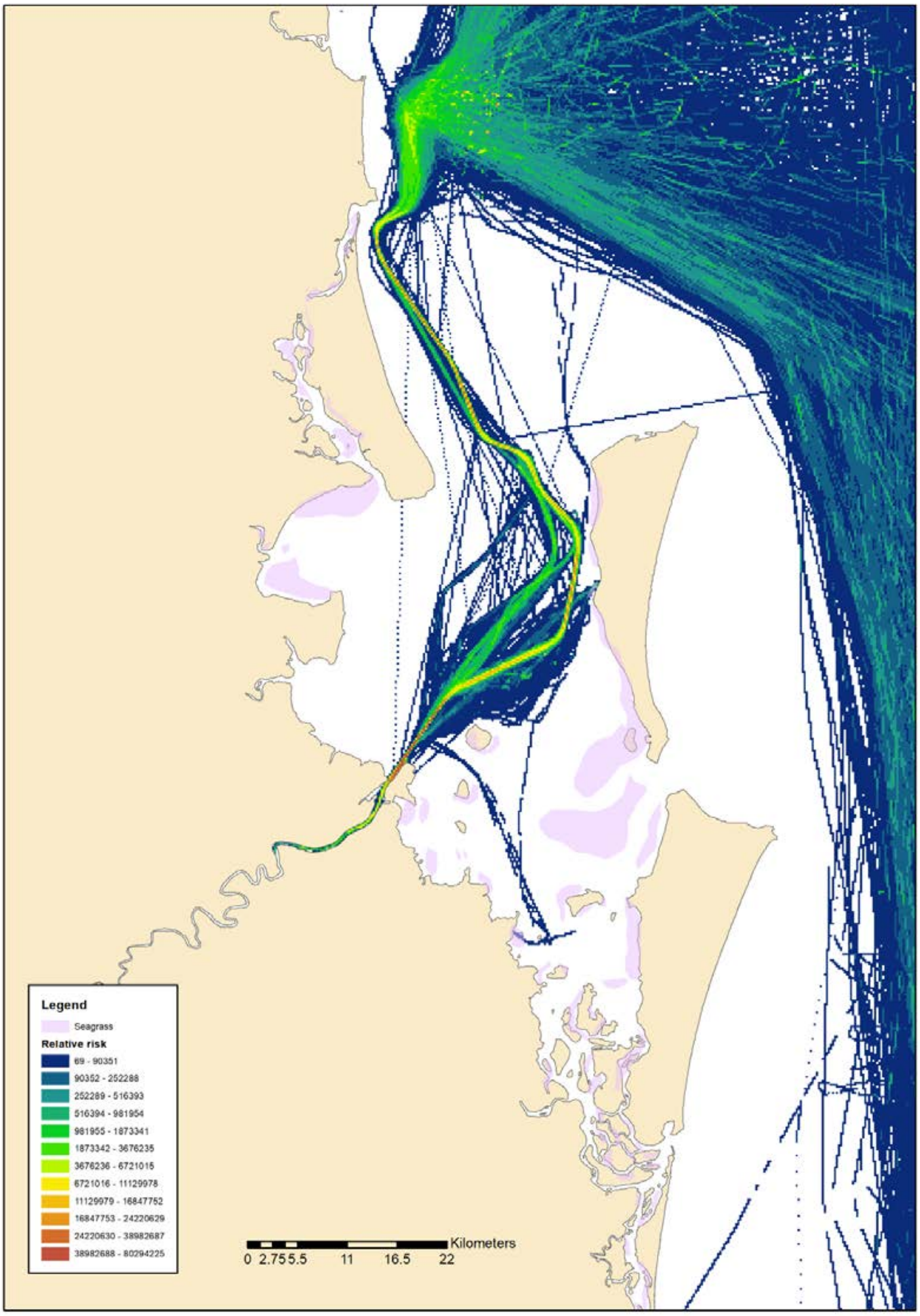
Appendix Table 13 Sources of uncertainty/variation

Source of Uncertainty	Description
Animal density uncertainty	The animal density estimates used in any of the models contain a suite of uncertainty. - Detection probability - Surface availability - Model mis-specification - Environmental covariate resolution and measurement error - Variable selection - Temporal variation (e.g., within season and inter-year variability) - Sampling error (e.g., you are not taking a population census but rather a sample of the population and extrapolating)
Vessel density uncertainty	Depending on how information on vessel density is obtained, this can also be a source of uncertainty. A common source of information is AIS. Around ports/population centres AIS polling is generally supplied by land stations and the vessel location can be inferred quite accurately. However, in other areas where AIS is recorded by satellite the polling frequency can be more erratic or less frequent. In this case you can still interpolate the paths with straight lines but there is much greater uncertainty on where the vessels actually went.
Collision model validity and uncertainty	Generally little is known about how animals and vessels interact at a fine-scale, and the mechanisms of collision. Any collision model is an approximation and will have associated variation both in terms of whether the model itself is a valid approximation and even if it is there will be variance/uncertainty.
Unknown animal responsive behaviour	Often little is known about animal responses to vessels on a local scale (e.g., they can avoid or actually move toward an oncoming vessel) or on a medium scale that animals avoid or are attracted to denser shipping routes (i.e., due to noise). Most current work seems to assume zero avoidance. This may be a legitimate assumption but most likely it will not be absolute and there would be some variation
Animal dive/surface availability	For diving animals, the animal must be near the surface either directly at the depth of the hull or close enough to be pulled up to the collision zone or into the propeller. Some species have studies using focal follows or depth tag data to estimate surface availability. However, there will be variation: between individuals, between sub-groups (e.g., mother calves vs adults) and by location (e.g., migratory corridor vs breeding or feeding areas). Furthermore, with most of these studies there can be sampling

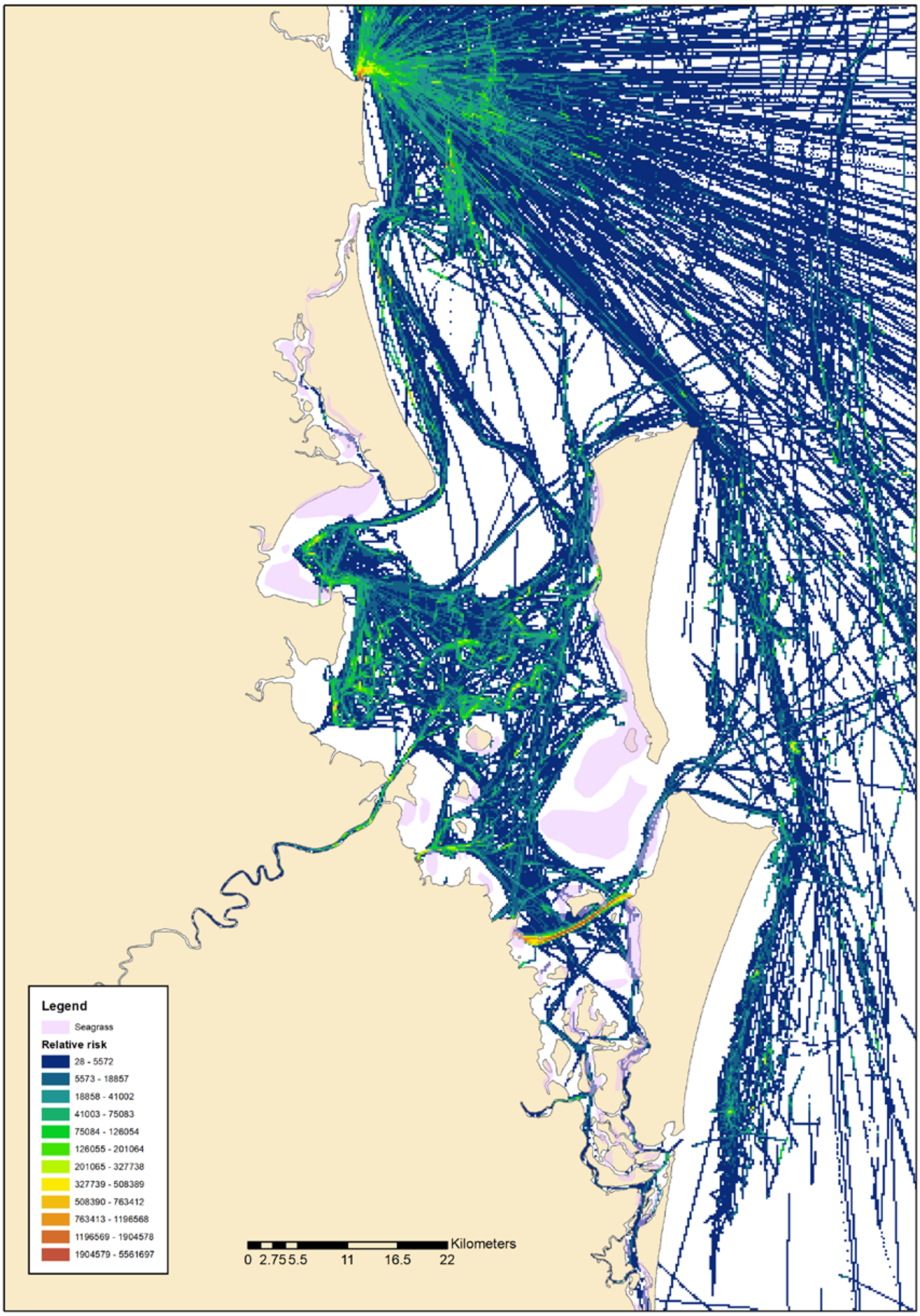
Source of Uncertainty	Description
	bias (i.e., animals that surface a lot and in a certain way are easier to tag and easier to focal follow). Furthermore, often, due to these differences, using information from published studies in a different area can introduce bias/uncertainty.
Vessel draft and characteristics	The vessel draft will affect the depth at which an animal will either collide with the hull or be sucked up into a collision. This type of data can be hard to reliably obtain, especially as it changes depending on loading and even sea temperature and salinity. It is reported in AIS but is often unreliable.
Vessel speed	Vessel speed is an important factor and is often known, via AIS, either from instantaneous speed reported in the AIS when polled, or calculated speed as an average between polls. Either way there can be some uncertainty/variation around the speed used in the modelling.
The model to link vessel speed to lethality	In most cases, very little is known about the probability of a fatality given a collision/vessel speed. For whales, the fatality curve of Vanderlaan and Taggart (2007) seems to have been universally used to map collisions to fatalities. Given the lack of knowledge, this curve provides the best measure. However, it has uncertainty associated with it. Firstly, it is a fitted model to empirical data so will have sampling error/model parameter uncertainty. Secondly, the data used is from a suite of observations from large whales of many species. It may not be likely, but it is possible there is a difference between species or heterogeneity within the population e.g., male vs female, size, calf versus adults. Also type of vessel is an unknown covariate. For example, navy vessels with different hull design and propulsion positioning may hypothetically have a different fatality probability curve than say cargo vessels. Single hull versus multihull passenger vessels etc.

APPENDIX F – EXAMPLES OF FINESCALE RISK MAPS

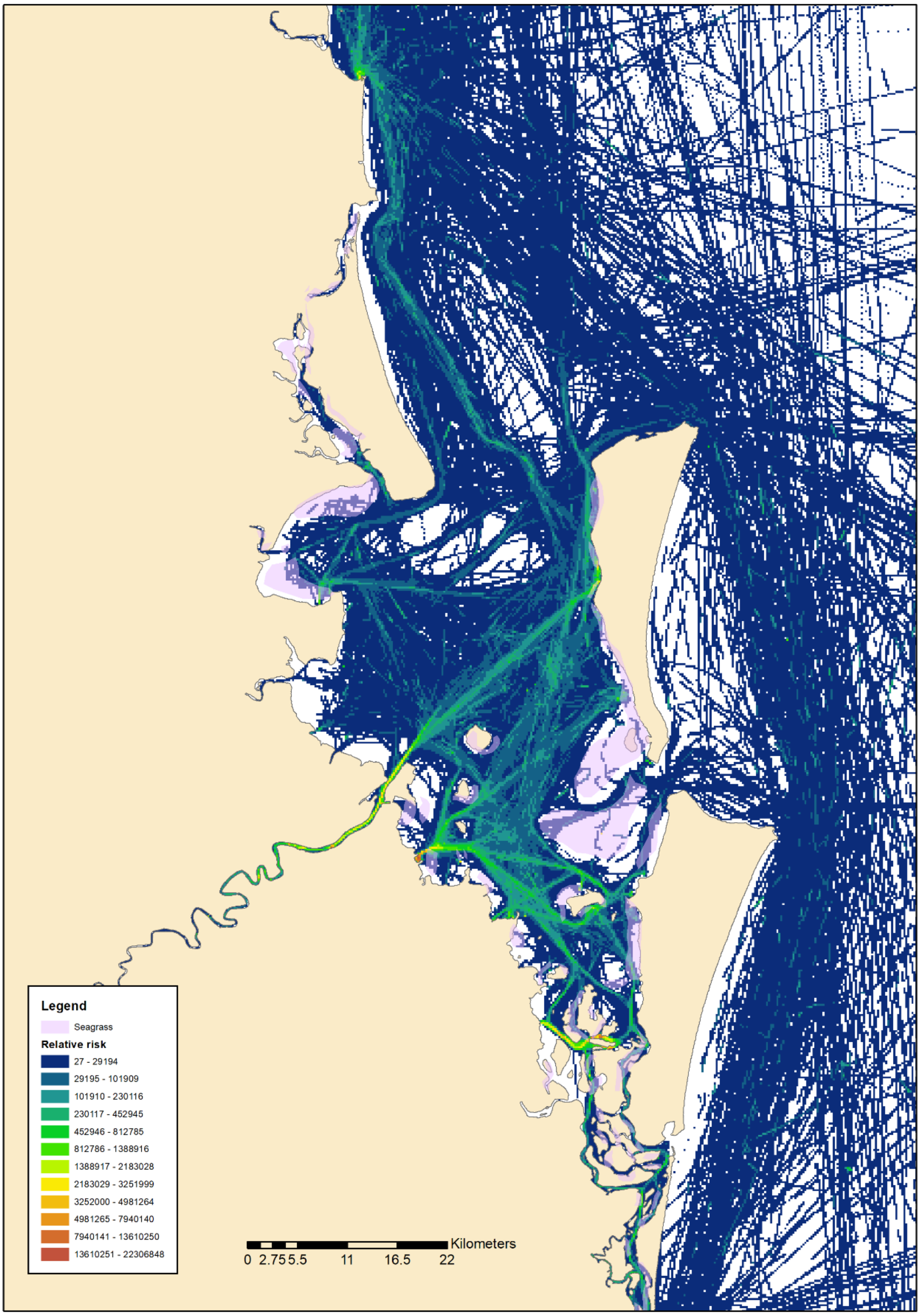
These maps are below the spatial resolution of the AIS subsampled data we use (see Section 3.3.1). However, these examples show how powerful the data can potentially be.



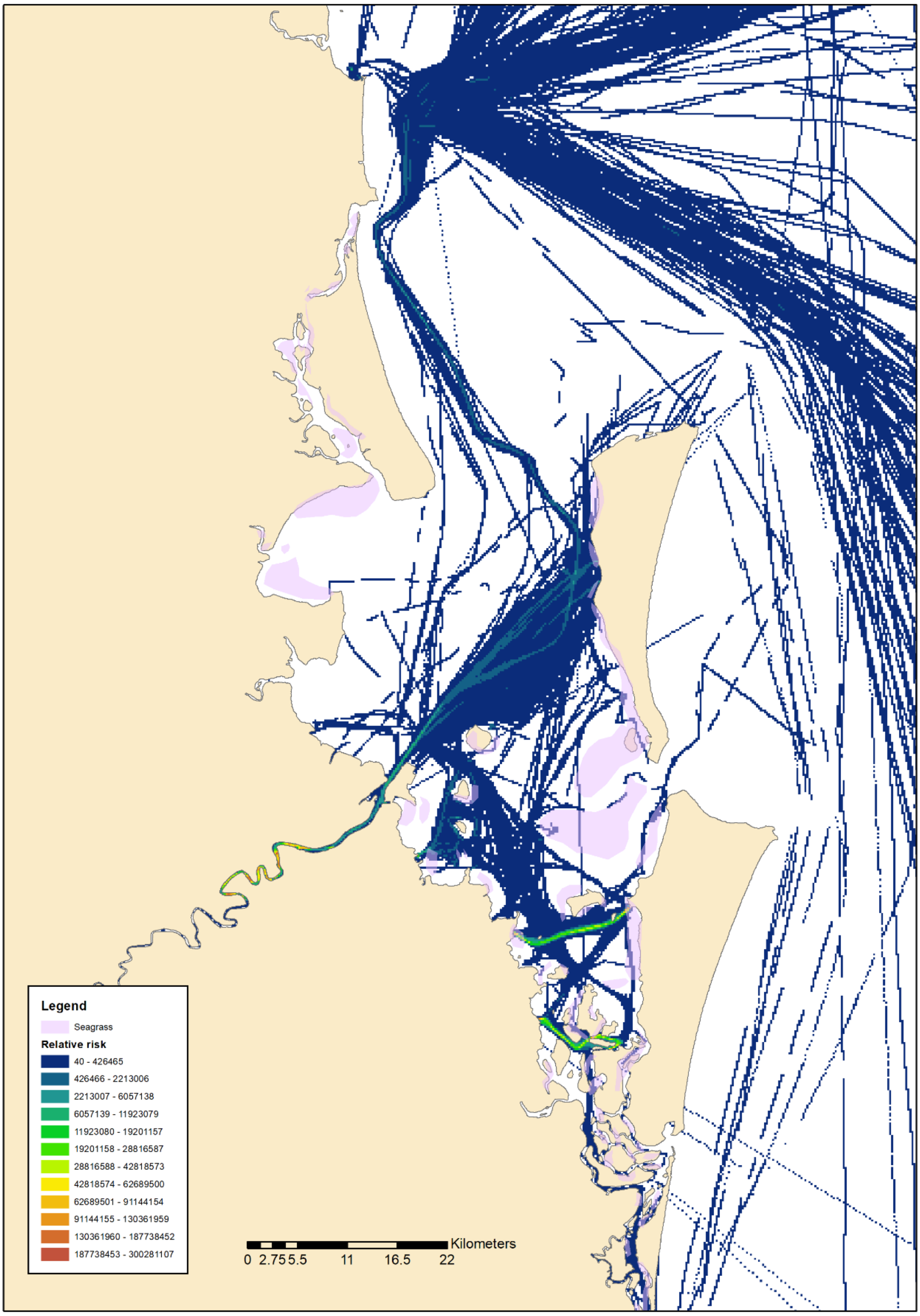
Appendix Figure 22 Example of fine scale map, non-specific species relative risk of a collision with AIS equipped Cargo vessels in Moreton Bay over 2015.



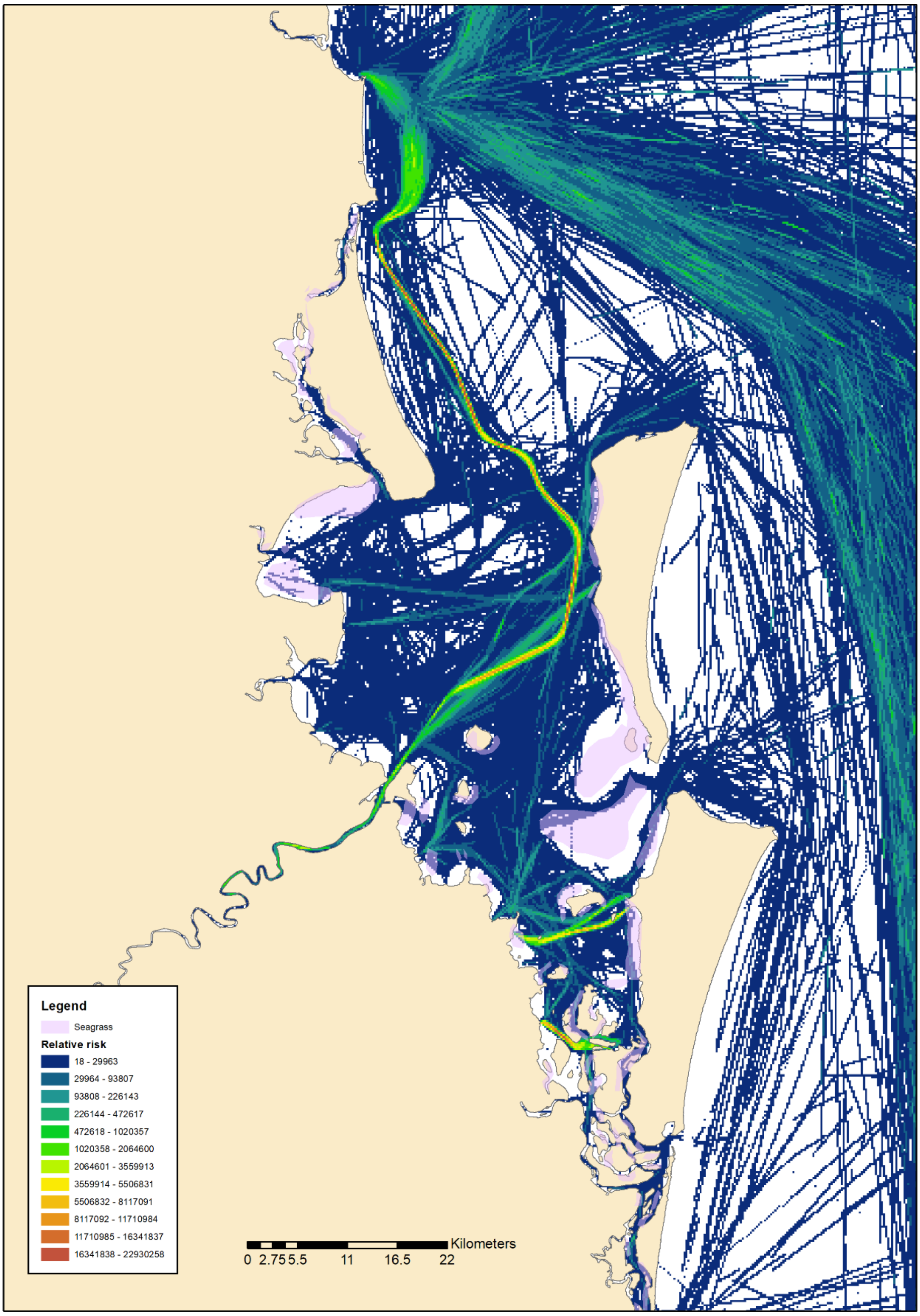
Appendix Figure 23 Example of fine scale map, non-specific species relative risk of a collision with AIS equipped Fishing vessels in Moreton Bay over 2015



Appendix Figure 24 Example of fine scale map, non-specific species relative risk of a collision with AIS equipped Recreational vessels in Moreton Bay over 2015



Appendix Figure 25 Example of fine scale map, non-specific species relative risk of a collision with AIS equipped Passenger vessels in Moreton Bay over 2015



Appendix Figure 26 Example of fine scale map, non-specific species relative risk of a collision with AIS equipped vessels travelling faster than 15kts in Moreton Bay over 2015

www.nespmarine.edu.au

Contact:
David Peel
CSIRO

Address | Castray Esp., Hobart, Tasmania
email | david.peel@csiro.au
tel | +61 3 6232 5179