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Risk Assessment of the potential impacts of seismic air gun surveys on marine finfish and invertebrates in Western Australia

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Terms, Acronyms & Abbreviations

ALARP	As low as reasonably practicable
APPEA	Australian Petroleum Production and Exploration Association
ARMA	Aquatic Resources Management Act 2016
C	Consequence level
DMP	Department of Mine and Petroleum
DPIRD	Department of Primary Industries and Regional Development
EBFM	Ecosystem-based Fisheries Management
EP	Environment Plan
ERA	Ecological Risk Assessment
ESD	Ecologically-Sustainable Development
ETP	Endangered, threatened or protected
Fisheries	Department of Primary Industries and Regional Development, Science and Resource Assessments Division, Fisheries Division
FRDC	Fisheries Research and Development Corporation
FRMA	*Fish Resources Management Act 1994*
L	Likelihood level
NOPSEMA	National Offshore Petroleum Safety and Environmental Management Authority
OCS	Offshore Constitutional Settlement 1995
WA	Western Australia
WAFIC	Western Australian Fishing Industry Council

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We would like to thank invited stakeholders for their participation in the risk assessment workshop on impacts of seismic surveys on marine finfish and invertebrates and associated reporting

1 Executive summary

Seismic surveys have the potential to affect marine life, including commercially and recreationally important finfish and invertebrate species and their prey. There is, however, considerable uncertainty around the degree of impact and relevant pressure-response pathways across the different taxonomic groups.

In order to gain a contemporary understanding of the seismic activity-related risks and potential impacts on finfish and invertebrates in waters off Western Australia, an assessment of risks posed by seismic surveys on finfish and invertebrates was facilitated by the Fisheries Division of the Department of Primary Industries and Regional Development (DPIRD) on December 7th, 2016. This took the form of an ecological risk assessment (ERA) workshop attended by 23 external stakeholders. The risk assessment involved estimating the level of risk associated with seismic surveys on the survival and/or the reproductive capacity of marine finfish and invertebrates individuals closest to the seismic source, for a period of 12 months directly following exposure.

The risk analysis methodology utilised for the 2016 risk assessment was based on the global standard for risk assessment and risk management (AS/NZS ISO 31000). This methodology utilised a consequence-likelihood analysis, and involved the examination of the magnitude of potential consequences from seismic surveys and the likelihood that those consequences will occur.

During the workshop, risk scores were allocated based on the collective knowledge and expertise of participants present at the workshop. This report summarises the outcomes of the risk assessment workshop and documents the assumptions discussed and agreed, the risk ratings allocated and the justifications for risk scores and ratings.

Overall the risk assessment found that the greater the intensity of sound and shallower the depth of water, the greater the assigned risk. In waters <250m, the risk ratings ranged from 'negligible' to 'severe' depending on depth, resource type and seismic intensity. The organisms classified as most at risk from seismic impacts were immobile invertebrates (e.g. molluscs) whereas pelagic fish were rated as the least at risk. For all fish and invertebrates, the impacts of seismic surveys, in waters deeper than 250m was assessed as acceptable (i.e. 'moderate' or lower).

This risk assessment on the impacts of seismic activity was undertaken at the level of individual adult finfish and invertebrate organisms closest to the seismic source. It represents the first step in estimating the broader impacts seismic surveys may pose at larger spatial scales. To assess the impacts at the level of populations, management units or fisheries a guidance statement is currently being developed by Fisheries. This will provide additional information for proponents when submitting applications for future surveys. It is anticipated the new guidance statement will be finalised in 2018.

2 Background

Marine seismic surveys are a prospecting tool used by the petroleum industry for locating favourable geological formations for determining undersea oil and gas deposits (Miller and Crisps 2013). Surveys typically involve the use of airgun arrays which are towed behind a vessel and produce high intensity, low-frequency sounds at regular intervals. Long strings (kilometres) of hydrophones pulled behind the air gun array detect the reflected signals. These data provide information about the seafloor and its underlying geological formations (Anon 2011, Carroll et al. 2016, Popper and Hastings 2009).

Seismic surveys have the potential to affect marine life, including commercially and recreationally important finfish and invertebrate species, their prey and the business activities of the fishers who harvest these aquatic resources. All stakeholders have access to aquatic resources, as long as the impacts of that access from all users of the marine environment are minimised and acceptable. The Department of Primary Industries and Regional Development, Fisheries Division (Fisheries) is responsible for: (i) delivering ecologically sustainable management and development of the State's aquatic resources; and (ii) the development of strategies and plans for the conservation of aquatic resources and the protection of aquatic ecosystems. The Offshore Constitutional Settlement 1995 (OCS) extends these responsibilities to Commonwealth waters off Western Australia. These responsibilities are legislated at the State level in WA under the *Aquatic Resources Management Act 2016 (ARMA)* which is set to replace the *Fish Resources Management Act 1994* (FRMA) and the *Pearling Act 1990* (Pearling Act) in the near future.

In State waters, marine organisms not covered by WA legislation are protected under the *Biodiversity Conservation Act 2016* administered by the Department of Biodiversity, Conservation and Attractions (DBCA). In Commonwealth waters listed marine organisms are protected under the *Environment Protection and Biodiversity Conservation Act* (EPBC) *1999* administered by the Department of Environment and Energy.

In State waters, the regulation of seismic surveys is managed through the *Petroleum (Submerged Lands) (Environment) Regulations 2012* and the Petroleum and *Geothermal Energy Resources (Environment) Regulations 2012* administered by the Western Australian Department of Mines, Industry, Regulation and Safety (DMIRS). In Commonwealth waters, the *Offshore Petroleum and Greenhouse Gas Storage (Environment) Regulations 2009* apply, as administered by the National Offshore Petroleum Safety and Environmental Management Authority (NOPSEMA). Prior to undertaking seismic surveys, titleholders are required to have an environment plan (EP) approved by DMIRS in State waters or accepted by NOPSEMA in Commonwealth waters.

With respect to the evaluation and mitigation of environmental impacts and risks, EPs are required to:

- provide a comprehensive description of the proposed activities;
- describe the existing environment (including social, economic and cultural features) and include details of its values and sensitivities;
- contain details of the environmental impacts and risks;
- include an evaluation of all impacts and risks, appropriate to the nature and scale of the activity; and
- provide details of the control measures that will be used to reduce the impacts and risks of the activity to levels that are 'as low as reasonably practical' (ALARP) and acceptable. This includes setting appropriate environmental performance objectives/outcomes performance standards and measurement criteria).

Approval or acceptance of EPs also requires the regulator to be satisfied that there has been an appropriate level of consultation with relevant authorities, persons and organisations. Titleholders are required to provide relevant persons with sufficient information and time to allow them to make an informed assessment of the possible consequences of the activity on their functions, interests or activities. Fisheries currently provides titleholders with generic advice in the form of a guidance statement (DoF 2013)[1], and with proposal-specific advice as part of the consultation process with respect to EPs as set out above. In addition, titleholders are directed to consult directly with potentially affected fishers, the Western Australian Fishing Industry Council Inc. (WAFIC) and other representative groups, such as the Pearl Producers Association, where relevant.

Fisheries manages aquatic resources according to a risk based approach, in accordance with the principles of Ecologically Sustainable Development (ESD) and Ecosystem Based Fisheries Management (EBFM). This risk based approach considers all ecological resources, the various users of these resources, and a broad range of community values in determining an appropriate level of management to ensure an acceptable level of risk is achieved. Accordingly, the Fisheries expectations as to how titleholders assess the impacts, and the acceptability of those impacts, will vary according to the level of risk.

To improve the understanding of risks associated with seismic survey activities to fish and invertebrates, Fisheries facilitated a risk assessment workshop involving a broad range of stakeholders on December 7th 2016 (Appendix 1). The risk analysis methodology was based on the global standard for risk assessment and risk management (AS/NZS ISO 31000). This methodology utilises a consequence-likelihood analysis, which involves the examination of the magnitude of potential consequences from seismic survey-related activities and the likelihood that those consequences will occur.

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[1] Note that Fisheries has commenced a review of its 2013 *Guidance statement on undertaking seismic surveys in Western Australian waters.*

2.1 Scope and purpose

The scope of this risk assessment was to estimate the level of risk, associated with seismic air gun surveys on the survival and/or the reproductive capacity of marine invertebrate and finfish individuals on the seismic acquisition line (i.e. directly underneath the path of the vessel) up to 12 months after seismic exposure. The scope does not extend to risks of impact on a larger scale (such as those on the level of regional aggregations, fisheries, management units or populations), nor does it consider cumulative impacts (i.e. multiple surveys over the same area) both, which will be addressed in a new Fisheries guidance statement, due for completion in 2018. This risk assessment also does not assess the impacts of seismic surveys on other organisms, e.g. marine mammals, sharks and rays, reptiles, zooplankton and corals. Nor does it assess the impacts of seismic surveys on fisheries – i.e. right of way issues and immediate impacts on catches.

This report summarises the outcomes of Fisheries' risk assessment workshop. The report documents the assumptions that were discussed and agreed (Sections 3.2 and 3.3), documents the risk ratings allocated during the workshop and captures the justifications for risk scores and ratings (Section 4).

The report has been thoroughly reviewed, with an earlier draft sent to stakeholders to provide comments and suggestions, to ensure that it accurately documented the workshop outcomes. Stakeholder's comments were considered in the final document and a report summarising a response to submissions provided to stakeholders who provided comment (Appendix 2). It should be noted that no changes were made to the risk scores as these reflected the consensus position as agreed on the day.

The outcomes of the risk assessment will inform Fisheries advice and guidance provided to proponents and the regulators in relation to proposed seismic surveys in both State and Commonwealth waters. The outcomes of this risk assessment will also be used in the development of the new Fisheries guidance statement.

2.2 Impacts of seismic surveys to marine finfish and invertebrates

Over the past two decades the number of experimental studies investigating the impact of seismic sound on marine species has significantly increased with the findings of these studies synthesized in several recent reviews, i.e. Carroll et al. (2017) and Fisheries (2017). It is recommended that these two reviews are read in conjunction with this report, including the detailed appendices within both reports which tabulate all seismic related research. A list of potential impacts of seismic surveys on marine finfish and invertebrates is provided in Tables 2-1 & 2-2.

The impacts of seismic sound on marine species depends on the properties of the sound, the distance to the source and the physiological properties of the receptor (e.g. the absolute sensitivity and range of spectral hearing) (Popper and Hawkins 2012, Slabbekoorn et al. 2010). With respect to the properties of the transmitted sound wave, four properties need to be considered with respect to the impact of seismic sound on marine life, i.e.: relative pressure, frequency, particle motion and duration (i.e. impulse) (Carroll et al. 2017).

Extrapolation of experimental research to natural settings is challenging and needs to be done with some caution. Most experimental research has involved either laboratory or caged experiments or a focus on clearly visible impacts manifesting shortly after exposure. Impacts due to non-lethal effects (short or long-term) and cumulative impacts due to the confounding effects of multiple stressors (e.g. multiple exposure to seismic arrays, climate change or dredging) are poorly understood. All of these factors need to be interpreted in the context of realistic exposure scenarios, experimental limitations and field conditions. The lack of standard terminology and measurements also makes comparisons among studies challenging (Carroll et al. 2017).

Table 2-1 Potential impacts of seismic surveys on invertebrates

Life Stage	Impact type	Potential impact of seismic survey
Adults and juveniles	Mortality	Death up to 12 months after survey
	Physical Impacts	Auditory system damage (e.g. statocysts)
		Internal organ damage
	Physiological Impacts	Physiological impacts (e.g. metabolic rate)
		Immuno compromisation/susceptibility to disease
	Behavioural Impacts	Temporary stunning
		Mobility (e.g. tail extension, ability to right themselves)
		Startle or flight response/erratic swimming or burying
		Effects on breeding behaviour
		Acoustic masking
	Cumulative impacts and mortality	Cumulative effect of all physical and behavioural impacts on direct and indirect mortality
	Cumulative impacts and catchability	Cumulative effect of all physical and behavioural impacts on catchability of fish (e.g. reduction in catch rates due to migration out of the area)
Larvae and eggs	Physical Impacts	Yolk displacement/membrane perturbation
		Hearing/movement detection (e.g. statocysts)
		Body malformations (larvae)
		Rates of egg/larvae development
	Behavioural Impacts	Swimming behaviour (larvae)
		Acoustic marking (larvae)
	Cumulative impacts and mortality	Cumulative effect of all physical and behavioural impacts on direct and indirect mortality

Table 2-2 Potential impacts of seismic surveys on finfish

Life Stage	Impact type	Potential impact of seismic survey
Adults and juveniles	Mortality	Death up to 12 months after survey
	Physical Impacts	Lateral line damage
		Auditory system damage
		Damage to internal organs (e.g. swim bladder)
	Physiological impacts	Increased serum cortisol, glucose & lactate
		Hearing loss or hearing threshold shifts
		Elevated ventilation response
	Behavioural Impacts	Temporary stunning
		Startle or flight response/erratic swimming
		Change in vertical position
		Change in horizontal position
		Change in swimming behaviour
		Effects on breeding behaviour
		Acoustic masking
		Displacement (i.e. residency change)
	Cumulative impacts & mortality	Cumulative effect of all physical and behavioural impacts on direct and indirect mortality and reproductive capacity
	Cumulative impacts and catchability	Cumulative effect of all physical and behavioural impacts on catchability of fish (e.g. reduction in catch rates due to migration out of the fishing area, collapse of aggregations)
Larvae and eggs	Physical Impacts	Yolk displacement/membrane perturbation
		Disruption to hearing/movement detection
		Body malformations (larvae)
		Changes in egg/larvae development
	Behavioural Impacts	Changes in swimming behaviour (larvae)
		Acoustic masking
	Cumulative impacts and mortality	Cumulative effect of all physical and behavioural impacts on direct and indirect mortality

3 Risk Assessment methodology

Risk assessments offer a means to filter and prioritise various management issues and have been used in fisheries management in Australia for over a decade (Fletcher et al. 2002). The risk analysis methodology utilised for the seismic risk assessment was based on the global standard for risk assessment and risk management (AS/NZS ISO 31000), which has been adopted for use in a fisheries context (see Fletcher 2005 & 2015, Fletcher et al. 2002).

The risk assessment process is summarised Figure 3-1. The first stage, 'Establishing the Context' specifies the definition of risk, identifies which species will be assessed and delineates the geographical boundaries and the timeframe for the risk assessment (Section 3.2).

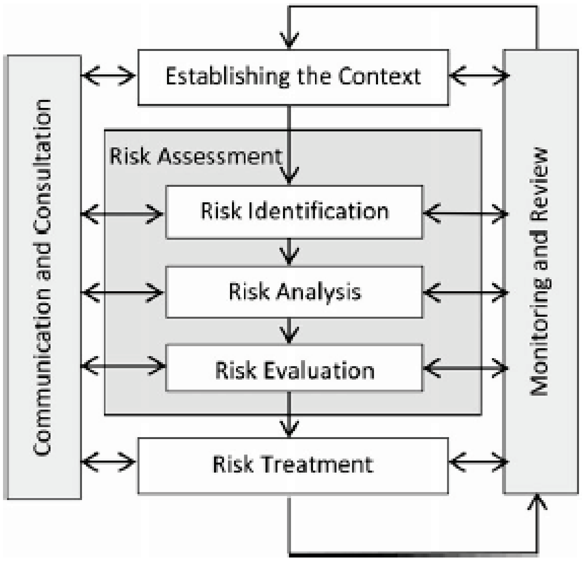

Figure 3-1. Position of risk assessment within the risk management process (modified from SA 2013)

Risk identification involves the process of recognising and describing risks, which includes the identification of risk sources and their causes (Section 3.3). Once the risks are identified they are scored by the risk analysis process. This involves examining each identified risk, the potential consequences (impacts) associated with each and the likelihood (probability) of each particular level of consequence actually occurring (Section 4). The combination produces a risk score.

Risk evaluation is 'the process of comparing the results of risk analysis against risk criteria to determine whether the level of risk is acceptable or tolerable' (AS/NZS ISO 31000 and ISO Guide 73). For the purposes of this risk assessment the term acceptable means an acceptable impact to adult finfish and invertebrate individuals which are directly on the seismic survey line. When a seismic survey is considered to pose a moderate or higher risk to individuals, the risk will be further assessed at a larger spatial scale, e.g. population, management unit, fishery or other appropriate spatial scale. The Fisheries guidance statement will provide information on how risk is undertaken on a larger scale.

Risk treatment typically involves management and mitigation strategies to reduce the risk to more acceptable levels. Risk treatment will occur at larger spatial scales through mitigating risk to groups of organisms, (e.g. avoiding key spawning grounds). Through mitigation and management, risk can potentially be reduced to a level that is both ALARP and acceptable as defined by the regulatory authorities (DMIRS and/or NOPSEMA). Further information on risk reduction strategies will be provided in the Fisheries guidance statement.

3.1 Consultation

An important part of the risk assessment and risk management process is achieving an agreed position among stakeholders on risk scores through communication and consultation. For the seismic risk assessment the consultation process involved:

- Prior to the risk assessment workshop distribution of:
    - A literature review examining the potential effects of seismic air gun surveys on marine finfish and invertebrates in WA (Fisheries 2017)
    - A background document explaining the risk assessment process and identification of issues to score for risk
    - The most recent peer-reviewed literature on the risk assessment process (Fletcher 2015)
- A risk assessment workshop with the participation of a broad range of stakeholders (See Appendix 1).
- Production of a risk assessment report (this report) summarising the results of the workshop. An earlier draft of this report was subject to stakeholder consultation. All comments were considered by Fisheries and stakeholders who provided comment were sent a response to submissions.

3.1.1 Workshop presentations

At the start of the workshop several presentations were made to provide background information:

- Dr Shaun Meredith, DPIRD, Fisheries, Introduction
- Mr Andrew Long, Petroleum Geo-Services – Seismic survey overview
- Professor Robert McCauley, Curtin University, Seismic surveys and biological impact mechanisms
- Dr Jayson Semmens, University of Tasmania, Research Outcomes: Impacts of seismic sound to southern rock lobster and commercial scallops
- Petrina Raitt Green Light Environmental, APPEA, Outcomes of the review: Underwater Sound and Vibration from Offshore Petroleum Activities and their Potential Effects on Marine Fauna: An Australian Perspective

3.2 Establishing the context

For the purpose of this assessment the term 'risk' relates to the potential direct and indirect impacts on an individual's survival or ability to breed as a result of being in the direct acquisition line of a seismic survey. Risk was assessed for impacts on adult individuals, due to a lack of information and knowledge on potential impacts to egg or larval stages. The timeframe for a potential impact was agreed to be up to 12 months after a survey, which typically allows sufficient time for one reproductive cycle.

The geographical extent of the risk assessment was for all State and Commonwealth waters off the coast of WA.

The scope of this Risk Assessment was for the next five years through until December 2022. It is necessary to periodically update the risk assessment, at least every five years, in order to take into account new information and research. For example, the risk assessment will need to be updated once the outcomes of a recently initiated three year research program, led by the Australian Institute of Marine Science (AIMS) on the effects of seismic surveys on marine life in northern WA is completed.

3.3 Issue identification (Component trees)

One of the first steps in the workshop process was the identification of relevant issues to be assessed for risk. This step is equivalent to the 'hazard identification' process used in most risk assessment procedures. In this assessment issue identification was assisted using the component tree approach (Fletcher et al. 2002) based on:

- Fisheries literature review on impacts of seismic activities on marine finfish and invertebrates (Fisheries 2017);
- Consultation with industry and external stakeholders during the workshop on 7th December 2016.

The identified issues were assessed for risk for each situation within a matrix of categories covering three major areas, i.e. aquatic resource type, water column depth and seismic sound intensity.

1. *Aquatic resource type*

Currently information on impacts to marine species is limited and nor is it logical or feasible to examine impacts to all species. Therefore risks associated with seismic surveys were assessed based on four fisheries-relevant categories of aquatic resource:

- Invertebrates, mobile
- Invertebrates, immobile
- Finfish, demersal
- Finfish, pelagic

2. *Water column depth*

Risks of impact on marine organisms are also strongly dependent on the proximity of the receptor to the source. For simplification, it was agreed to estimate risk levels for receptors at four specific depths, broadly reflecting different habitat types and logistical constraints for seismic surveys, i.e.≥20m, 50m, 100m and >250m. These depth categories are indicative of seismic exposure as in reality depth is a continuum and exposure is proportional to the distance from the source.

3. *Seismic source strength*

For the purposes of this risk assessment, risk based was on three different seismic array volumes of <2000 in^3, 2000-4500 in^3, and ≥4500 in^3, and an average number of shots of 50-70 per km. These are representative parameters used during seismic surveys by oil and gas companies in WA. The volume of the air gun array is proportional to the level of sound produced and is indicative of the likely intensity experienced by a marine organism (IAOGP & IAGC 2011, McCauley et al. 2016). It was assumed that during a seismic survey an individual organism remains stationary (i.e. does not flee) and is positioned directly in the path line of the vessel, thus experiencing numerous pulses with varying degrees of intensity as the vessel approaches, passes overhead and moves further away[2].

Seismic surveys can also affect organisms through particle motion. Instruments to accurately measure particle motion have only recently become practical to use and analyse. In the absence of such measurements, it is common to use sound pressure (or in this case the volume of the array) as a proxy for particle motion as there is a correlation between the two (Fitzgibbon et al. 2017).

[2] Note the seabed environment also affects sound exposure; however, this information is not available throughout all WA marine areas and was not used in this assessment.

3.3.1 Component tree

The workshop involved assessing risk for each combination of categories, for example the effects of seismic surveys was assessed for each aquatic resource, each depth category and for each sound source intensity i.e. array volume (Figure 3-2).

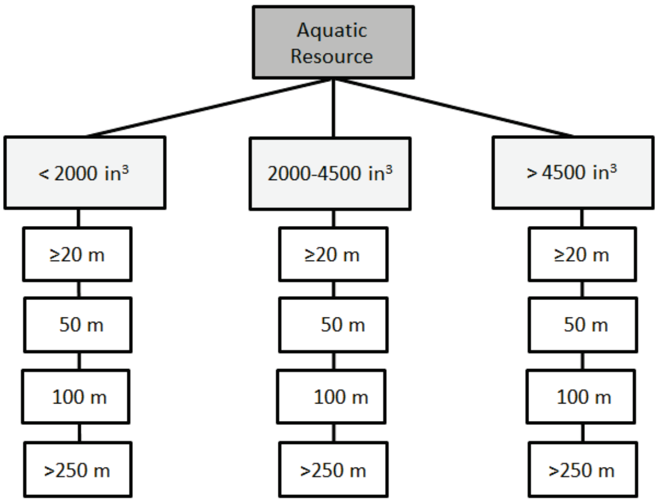

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Figure 3-2 Component tree/Diagram illustrating how risk was assessed for each combination of resource, air gun volume and depth.

3.4 Risk Assessment Process and Reporting

The risk assessment process assists in separating minor risks from major risks. It also helps to identify key species present within the survey area that may be more vulnerable to seismic impacts and for which: (i) impacts on larger spatial scales (e.g. at the level of the population or management unit) may need to be evaluated; and/or (ii) mitigation and management measures need to be defined.

Once the components and issues were identified for seismic activities, the process of evaluation was undertaken using the ISO 31000-based qualitative risk assessment methodology. This methodology utilised a consequence-likelihood analysis, which involved the examination of the magnitude of potential consequences from seismic activities and the likelihood that those consequences will occur (Fletcher 2015). Consequence and likelihood analyses range in complexity, in this assessment a 4 x 4 matrix was used (Table 3-1 and Table 3-2). Scoring involved an assessment of the likelihood that each level of consequence actually occurring or is likely to occur. The agreed scores for each of the consequence and likelihood levels were then multiplied to determine the risk score, i.e. Risk = the highest Consequence × Likelihood (Table 3-3).

Table 3-1 Consequence levels

Resource – measured at an individual level
1. Indirect* effects resulting in negligible level of mortality and/or effect on reproductive capacity (<2% of individuals)
2. Indirect and/or direct* effects resulting in 'low' level of mortality and/or effect on reproductive capacity (2-10% of individuals)
3. Direct and/or indirect effects resulting in 'moderate' level of mortality and/or effect on reproductive capacity (10-40% of individuals)
4. Direct effects resulting in 'large' level of mortality and/or effect on reproductive capacity (>40% of individuals affected)

Table 3-2 Levels of likelihood

Likelihood of each consequence over the next five years based the assumption impacts on mortality and/or reproductive capacity will occur within 12 months of seismic exposure. (Note: If not measurable, Likelihood Level is essentially 0)
1. Remote – Never heard of but not impossible here (< 5 % probability)
2. Unlikely – May occur here but only in exceptional circumstances (5-30%)
3. Possible – Clear evidence to suggest this is possible in this situation (30-50%)
4. Likely – It is likely, but not certain, to occur here (50-100%)

* **Indirect effects** relate to behaviour changes that lead to death or reduced reproductive capacity through increased predation, loss of prey access, disease etc. **Direct effects** relate to physical and/or physiological impacts that lead to death or reduced reproductive capacity

Table 3-3. Standard Consequence — Likelihood Risk Matrix (based on AS 4360 / ISO 31000; adapted from Fletcher 2015)

		Likelihood			
		Remote (1)	Unlikely (2)	Possible (3)	Likely (4)
Consequence	Minimal (1)	1	2	3	4
	Moderate (2)	2	4	6	8
	High (3)	3	6	9	12
	Major (4)	4	8	12	16

Table 3-4 Risk levels applied to assets (modified from Fletcher 2015)

Risk Category / Level	Description
1 Negligible	**Acceptable:** • Not an issue
2 Low	**Acceptable:** • No assessment of impacts at the population level for key species required. • No specific control measures needed.
3 Moderate	**Acceptable;** • Assessment of impacts at the population level for key species required. • Risk mitigation and control measures potentially required
4 High	**Below acceptable;** • Assessment of impacts at the population level for key species required. • Risk mitigation and risk control measures likely to be required
5 Severe	**Well below acceptable;** • Assessment of impacts at the population level for key species required. • Risk mitigation and risk control measures very likely to be required

The formal risk analysis was undertaken at a stakeholder workshop held on December 7th 2016 at the WA Fisheries and Marine Research Laboratories in Hillarys, Perth. Stakeholders invited to the workshop included representatives from Australian Petroleum Production and Exploration Association (APPEA), the Oil and Gas Industry, the Western Australian Fishing Industry Council, the Pearl Producers Association, Recfishwest, the Australian Institute of Marine Science, Geoscience Australia and various research institutes throughout Australia including Curtin University and University of Tasmania (Appendix 1). Workshop participants estimated the risk level for each issue, based on the judgements of participants at the workshop, who collectively were considered to have appropriate expertise in the subject areas being assessed.

A risk score calculated for each combination of resource, depth and sound source was assigned one of five risk categories: Negligible (blue), Low (green), Medium (yellow), High (orange) or Severe (Red) (Table 3-4). The discussion and justification including any disagreements for classifying issues at each risk level was documented at the workshop and formed the basis of this report.

For each aquatic resource the report is structured as follows:

- Table providing risk scores and risk levels as scored by participants in the workshop
- Workshop discussions and justifications for scores
- Summary of research referred to in workshop discussions.
- Other research on seismic impacts

During the workshop risk scores were primarily based on the effects of seismic sound on Australian species (Day et al. 2016[3], McCauley et al. 2000 & 2003a, Miller and Crisp 2013). To provide information and context the section "Summary of research referred to in workshop discussions" has been included. Prior to the workshop participants were provided with review on the impacts of seismic to marine organisms (Fisheries 2017). For completeness a post workshop review of "Other research on seismic impacts" is also included in this report which includes two recent reviews completed in 2017.

[3] Subsequent to the workshop, some of the research by Day et al. 2016 has been published in peer reviewed journals. As these publications were not available at the time of the workshop they have not been cited here.

4 Risk Analysis

4.1 Mobile invertebrates (e.g. crabs, prawns, lobsters)

Table 4-1 Risk scores and risk ratings for mobile invertebrates as scored in the workshop

	Air gun array volume(in^3)		
Depth (m)	**<2000**	**2000-4500**	**>4500**
≥ 20	C3, L3 = 9 (HIGH)	N/A	N/A
50	C3, L2 = 6 (MODERATE)	C3, L3 = 9 (HIGH)	C4, L3 = 12 (SEVERE)
100	C2, L2, = 4 (LOW)	C3, L2 = 6 (MODERATE)	C3, L3 = 9 (HIGH)
>250	C2, L1 = 2 (NEGLIGIBLE)	C3, L2 = 6 (MODERATE)	C3, L2 = 6 (MODERATE)

4.1.1 Risk justification – workshop discussions

The risk ratings on mobile invertebrates (Table 4-1) were mainly based on the experimental studies which examined impacts of seismic surveys on the southern rock lobster (*Jasus edwardsii*) (Day et al. 2016).

The risk scores were attributed to the sub-lethal impacts of air guns on the lobsters, in particular the reduced ability to right themselves and capacity for tail extension. During the scoring process workshop discussions considered these indicators of stress likely to have an indirect effect on lobster survival and reproductive output, potentially by affecting other behaviour such as feeding, mating and predator avoidance.

The impacts on lobster physiology and implications of reduced haemocytes and nutritional index were less clear but could possibly result in reduced immunity and general health status. Due to the uncertainty of these physiological effects on lobster survival the risk of seismic impacts was conservatively scored higher in the workshop.

The risk of impacts associated with seismic activity was considered to be greater in shallower waters and reduce with depth due to attenuation of sound with distance from the source. Risks increased with increasing size of the sound source.

4.1.2 Summary of research referred to in workshop discussions

The impact of seismic surveys on lobsters was based on research undertaken on the southern rock lobster in Tasmania in a coastal location 10-12 m deep (Day et al. 2016). Lobsters were held in cages and exposed to a single compressed air source of two different volumes (45 in^3 or 150 in^3 gun), at a pressure of either 1300 psi or 2000 psi. Experiments were undertaken in the summer and winter. Estimates of sound received were made at the lobster pots. The estimates of cumulative sound loading ranged between 191 – 199 re 1 $\mu Pa^2 \cdot s$, depending on source and pressure (see page 55, Day et al. 2016). These exposures were estimated to approximate those of a commercial ~ 3100 in^3 seismic source passing within 100-500 m range adjacent the lobsters.

Day et al. (2016) found no evidence of any direct impacts on lobster survival in any of the experiments. While no direct mortality was recorded, variable sub-lethal effects were observed with impacts differing depending on a range of factors including: season, air gun size and air pressure, time after exposure and lobster source location (i.e. the location where lobsters were collected). The greatest impacts or worst case scenario was used in the risk rating process.

The first sub-lethal impact was reduced tail extension, which was considered to be symptomatic of fatigue (Spanoghe and Bourne 1997). Lobsters exposed to air guns at 150 in^3 2000 psi in summer demonstrated a reduced capacity for tail extension for up to 14 days after seismic exposure. The second and more significant, sub-lethal impact was a lag in the righting response, measured as the time it takes for a lobster to right itself after being placed on its back. Lobster righting response is a complex reflex requiring neurological control and muscle coordination (Stoner 2009). The study found that exposure to 150 in^3 air gun at 1300 psi, increased the righting time for lobsters by up to twice compared to lobsters which were not exposed. The effects on righting time persisted for up to 365 days post exposure, even after a moult, suggesting the effects may be permanent (Day et al. 2016).

The cause of the delayed righting response was attributed to damage to the sensory hairs in the statocyst, the principle balance sensory organ in lobsters located in the base of the antennules. Significant damage to hair cells was observed in most of the experiments using either the 45 or 150 in^3 gun, and at 1300 and 2000 psi. Statistical analysis showed that the damage was correlated to impaired righting time, with greater damage resulting in slower righting (Day et al. 2016).

The consequences of reduced tail extension and increased righting time on lobster health, survival and reproduction are not known but behaviours associated with feeding, predator avoidance, locomotion, social behaviour and reproduction may be negatively affected.

Seismic exposure was also shown to have impacts on lobster physiology through impacts to lobster haemolymph. Haemolymph is the invertebrate analogue to vertebrate blood carrying out functions such as transport of oxygen, waste and nutrients and mediating immune response. Two impacts were observed, the first was a reduction in the refractive index of the haemolymph which is a measure of nutritional condition indicating how well lobsters are able to consume, digest and assimilate food. The refractive index was significantly reduced in one of the treatments involving the 150 in^3 gun at 1300 psi at 120 and 365 days post exposure. The other five experimental treatments showed no significant effect. The second response was a reduced haemocyte count, in all treatments, with one treatment showing impacts up to 365 days post exposure. Decreases in circulating haemocytes typify the response to trauma or stress and can leave the lobster vulnerable to infection (Day et al. 2016).

4.1.3 "Other" research on seismic impacts to mobile invertebrates (excluding squid)

Other research has also not found any evidence of increased mortality due to airgun exposure on invertebrates including lobsters (Parry and Gason 2006, Payne et al. 2007), snow crabs (Christian et al. 2003) and shrimps (Andriguettto-Filho et al. 2005).

Behavioural changes have been observed in other invertebrates in response to seismic sound. Decapods have been demonstrated to show a startle response to airguns, but only when they were < 10cm from the sound source. No response was observed for decapods at distances of 1 m or more (Christian et al. 2003, Goodall 1990). Sound avoidance may have more lasting impacts on populations particularly if animals migrate out of an area in which seismic surveys are conducted however no such behavioural response was observed in snow crabs (Christian et al. 2003) or in shrimp (Celi et al. 2013). Other studies on righting times in the American lobster (*Homarus americanus*) found no differences in righting times after exposure to 202 -227 dB 1 µPa at a distance of 2m from the source (Payne et al. 2007).

Seismic sound has also been demonstrated to cause physiological impacts on invertebrates. A study on crabs found an increased oxygen consumption rate in large crabs (Wale et al. 2013a & b), however, studies on the effect of seismic noise on metabolic rates has found no clear evidence of seismic sound on food consumption rate in lobsters (Payne et al. 2007).

Research into impacts on invertebrate haemolymph in response to seismic sound has found no impacts in the American lobster (Payne et al. 2007) or snow crab (Christian et al. 2003 and 2004). Shipping noise has been shown to increase glucose, total protein, heat-shock proteins, and total haemocyte count in lobster (Filicotto et al. 2014).

4.2 Immobile invertebrates (e.g. pearl oysters, scallops, trochus, sea cucumbers)

Table 4-2 Risk scores and risk ratings for immobile invertebrates as scored in the workshop

	Air gun array volume (in^3)		
Depth (m)	**<2000**	**2000-4500**	**>4500**
≥ 20	C4, L3 = 12 (SEVERE)	N/A	N/A
50	C4, L3 = 12 (SEVERE)	C4, L3 = 12 (SEVERE)	C4, L4 = 16 (SEVERE)
100	C3, L3 = 9 (HIGH)	C3, L4 = 12 (HIGH)	C4, L3 = 12 (SEVERE)
>250	C1, L4 = 4 (LOW)	C2, L2 = 4 (LOW)	C2, L3 = 6 (MODERATE)

4.2.1 Risk justification – workshop discussions

The risk scores on immobile invertebrates (Table 4-2) were mainly based on the results of research on seismic impacts to the commercial scallop (*Pecten fumatus*) (Day et al. 2016).

Mortality was considered a severe risk for scallops at certain depths, noting that the effects of seismic sound on physiology and survival may not be immediate but become more apparent with time (Day et al. 2016).

The WA pearl fishery currently collects wildshell in depths of <40m. The majority of the wild pearl shell is collected off 80 Mile Beach, and is used for pearl cultivation in farms in the Kimberley region. Wild shell may occur in waters >40m, however, deeper populations have not been investigated to date.

The risk of impacts associated with seismic activity were considered to be greater in shallower waters reducing with depth due to the attenuation of sound with distance. Risks were assessed as greater with higher sound source.

4.2.2 Summary of research referred to in workshop discussions

Research on the impact of seismic sound on scallops was undertaken as a part of the same project which examined the impact of seismic to lobsters, i.e. Day et al. (2016). This research used 45 and 150 in^3 guns, at 1300 and 2000 psi in 10-12m water depth. Scallops were exposed to a number of passes of the air gun, 0 (control) 1, 2 and 4 passes. Measurements of exposure varied between peak to peak 191-213 (dB re 1μPa), SEL 181-188 (dB re μPa^2·s) and SEL cumulative 189-197 (dB re 1 μPa^2·s). These exposure levels were suggested to be similar levels received during commercial seismic surveys. The impact on scallop health and survival was assessed at three different time periods following exposure 0, 14 and 120 days.

The research found no evidence of mass mortality in response to air gun exposure, with mortality rates found to be similar to natural annual mortality rates of 11-51%. However, the results did find repeated exposure, resulted in significantly increased mortality rates over a period of four months, compared to unexposed controls. Scallops exposed to 2 and 4 seismic gun passes were found to have an elevated risk of mortality over that of both the 0 and 1 pass treatments. The mortality was not immediate, with highest mortality occurring in the longer term, 120 days after exposure (Day et al. 2016).

Exposure to seismic air signals had significant effects on the physiology of scallops, particularly on the haemocyte count and haemolymph biochemistry. Scallop haemolymph is responsible for a number of functions, including oxygen and nutrient transfer, waste removal and immune response and is used as an indicator of health and stress response. Whilst the responses in scallop haemocyte counts were variable depending on the treatment, the largest changes were observed at day 120, with numbers decreasing to a level around half that of control scallops. Eight haemolymph electrolyte and mineral ions showed a significant response to exposure, with sodium, potassium, calcium and chloride showing overall trends of increasing concentration with repeated exposure and magnesium and bicarbonate showing decreasing concentration in response to exposure. Protein and glucose levels in the haemolymph also decreased with exposure. Other metabolites, organic molecules and enzymes showed no change. The disruption of the ability to control the concentration of electrolytes and minerals in the haemolymph indicates a compromised physiology, particularly as the impact persisted over the course of the entire experiment (day 120 post-exposure) (Day et al. 2016).

Scallop behaviour was also affected by seismic exposure including, positioning, mantle irrigation, righting and a flinching behaviour. Scallops showed a change in the rate at which they recess into the sediment, with the recessing rate increasing with the number of air gun passes. The most important finding from the recessing tests was that the impact persisted to the 120 day sampling point, indicating a chronic alteration in this reflex. Scallops which had been exposed to air guns were slower to right themselves, and a novel flinching behaviour, involving rapid retraction of the mantle velum was observed during exposure up to 350 m from the air gun source (Day et al. 2016).

The impacts of sub-lethal effects of seismic activities in terms of a scallops value to fisheries were also assessed. Five indices were compared between the different treatment levels, with no clear response in relation to seismic exposure observed in: mass-to-length, mass-to-volume ratios, tissue mass relative to total mass, adductor mass, total mass and tissue mass (Day et al. 2016).

4.2.3 "Other" research on seismic impacts to immobile invertebrates

Other studies have found no evidence of increased mortality or a change in the condition of the meat or roe quality in the commercial scallop *P. fumatus* in relation to air gun exposure (Harrington et al. 2010, Przeslawski et al. 2017). These studies differed to that of Day et al. 2016 in that they involved the use of a commercial array involving a seismic vessel and impacts were assessed in the short term (i.e. <2 months). These studies were also based on relatively low sound exposure levels (highest received was 146 dB re 1 $\mu Pa^2 \cdot s$).

There is evidence that seismic sound may affect behaviour of other molluscs. For example changes in bioturbation were observed in the clam *Ruditapes philippinarum* (Solan et al. 2016).

There are limited studies on the effects of seismic sound on immobile invertebrate physiology. The impacts on clams is variable: one study on the clam *Ruditapes philippinarum* which examined a range of invertebrates found no impacts of shipping noise or impulse noise on tissue levels of glucose or lactate (Solan et al. 2016), whereas another study on the clam *Paphia aurea* found increased levels of glucose, hydrocortisone, and lactate in the muscle and hepatopancreas in immediately after exposure to seismic airgun pulses (La Bella et al. 1996).

4.3 Finfish demersal (e.g. goldband snapper, red emperor, pink snapper)

Table 4-3 Risk scores and risk ratings for demersal fish as scored in the workshop

	Air gun array volume (in^3)		
Depth (m)	**<2000**	**2000-4500**	**>4500**
≥ 20	C3, L3 = 9 (HIGH)	N/A	N/A
50	C2, L3 = 6 (MODERATE)	C3, L3 = 9 (HIGH)	C4, L3 = 12 (SEVERE)
100	C2, L2 = 4 (LOW)	C3, L3 = 9 (HIGH)	C3, L3 = 9 (HIGH)
>250	C2, L1 = 2 (NEGLIGIBLE)	C2, L3 = 6 (MODERATE)	C2, L3 = 6 (MODERATE)

4.3.1 Risk justification – workshop discussions

During the workshop it was decided to focus on larger, commercially important demersal species rather than smaller species with less commercial significance such as damsel or anemone fish (Table 4-3). Risk scores were mainly based on the results of research on seismic impacts on two important demersal species in WA, pink snapper (*Chrysophrys auratus*) and goldband snapper (*Pristipomoides multidens*) (McCauley and Fewtrell 2008, McCauley and Kent 2012, McCauley et al. 2000, 2003a & b).

It was agreed in the workshop that the risk assessment of seismic impacts demersal fish would be based on two conservative assumptions. Firstly, it was assumed that demersal species do not swim away from a vessel undertaking a seismic survey. Whilst most species of fish can swim fast over short distances, it was assumed that most demersal species tire over longer distances and are unable to swim beyond seismic exposure. The second assumption was that fish have a swim bladder which is connected to the inner ear. Fish which have swim bladders and those which are connected to the inner ear are more susceptible to pressure mediated injury to ears than species lacking swim bladders (Carroll et al. 2016).

4.3.2 Summary of research referred to in workshop discussions

Experiments on the effects of seismic exposure to pink snapper has found evidence of extensive damage to the sensory hair cells surrounding the otoliths (McCauley et al. 2000). Experiments involved holding snapper in cages and exposing them to signals from an air gun towed toward and away from the cages, mimicking the stimulus from a passing seismic vessel. Hydrophones were used to record received air gun signals, which were mostly between 150-180 dB re 1µPa mean squared pressure. The higher sound exposure levels (i.e. 180 dB re 1µPa mean squared pressure) were considered comparable to what would be received to what would be expected at ranges < 500 m from a large seismic array (McCauley et al. 2000). The research found that damage was so severe to leave holes where the hair cells were ejected from the epithelia, and after 58 days the number of holes was 10 x higher than controls which were not exposed to seismic sound. On the first set of seismic passes that led to the hearing damage exposed fish showed a vigorous behavioural response, but 58 days later, the same fish failed to respond to seismic passes indicating either habituation or potential hearing damage (McCauley and Fewtrall 2008, McCauley et al. 2003b).

The study by McCauley et al. (2000) focused only on the anatomical impacts to the inner ear, and the consequences of damaged hair cells to long term survival and reproduction was not investigated. Fish with impaired hearing may have reduced fitness potentially leaving them vulnerable to predators, unable to locate prey, sense their acoustic environment, or, in the case of vocal fishes, unable to communicate acoustically (McCauley et al. 2003b).

A separate study on goldband snapper in the Timor Sea involved fish traps and a 3090 in^3 air gun array. The array was towed towards the fish traps, with fish experiencing a range of exposures depending the closest distance that the array was from the traps. The distances that the array was towed towards the traps were 370m, 2.1 km and 58 km at the closest air gun pass. The maximum sound exposure level in these experiments was 180 dB re 1 $\mu Pa^2 \cdot s$. Damage to the sensory epithelia was quantified and there was exponentially increasing hair cell damage with decreasing range from the sources or increasing cumulative sound pressure (McCauley and Kent 2012).

McCauley et al. (2003a) examined the effect of marine seismic surveys on humpback whales, sea turtles, fishes and squid. The effects of air gun signals were tested on 16 fish species with a range of responses observed. The received sound levels varied between 146-195 dB re 1 µPa mean square pressure in the different experiments. The observed responses were:

- Startle response especially in smaller fishes
- Alarm responses becoming more noticeable in response to increased intensity of air gun signals
- Lessening of severity of startle responses through time (habituation)
- Behavioural response (forming tighter groups, swimming faster, moving to the bottom of the cage) which increased in severity with increased exposure
- Evidence of fish fleeing an operating air gun above some tolerance level

- Damage to hearing system of exposed fishes in the form of ablated or damaged hair cells. However the exposure regime required to produce this damage was not established and it was believed such damage would require exposure to high level air gun signals at short range from the source
- No significant increases in stress (measured through blood cortisone levels) which could be directly attributed to air gun exposure.

In contrast to the research on pink and gold band snapper, a study involving a 3D seismic survey in northern WA, found no significant effects on the abundance or diversity on either site attached or free roaming demersal species (Miller and Crisp 2013). In this study fish were exposed to SELs of less than 187 DB re 1 $\mu Pa^2 s$ and impacts were examined through underwater visual consensus of the fish community, before and after the seismic survey. The underwater visual counts were combined with 10 years of historical monitoring data and no effects of seismic exposure were detected in terms of species richness and abundance (Miller and Crisp 2013).

4.3.3 "Other" research on seismic impacts to demersal finfish

There have been numerous studies on the effects of low frequency sound on a range of fish species (< 300 Hz) and two recent reviews (Carroll et al. 2017, Fisheries 2017). This research is summarised in Table 2-2 and the paragraphs below.

The majority of studies have not found air guns to affect finfish survival (Boeger et al. 2006, Dalen and Knutsen 1987, Hassel et al. 2003 & 2004, McCauley et al. 2003a & b, Popper et al. 2005 & 2016, Santulli et al. 1999, Thomsen 2002 and Wardle et al. 2001).

While seismic surveys have not been shown to directly impact on demersal finfish survival, some studies have found evidence of physical impacts of seismic sound at high exposure levels (i.e. 208-246 dB re 1 μPa^2) swim bladder damage (Falk and Lawrence 1973, Holliday et al. 1987, Weinhold and Weaver 1972), internal bleeding or damage to blood cells including eye injuries (Kosheleva 1992), blindness (Matishov 1992) and injury to sensory cilia of the lateral line (Booman 1996). Other studies have found impacts to sensory epithelia attached to the otolith, at exposure levels up to 185 dB re 1 μPa^2 (McCauley and Fewtrall 2008, McCauley et al. 2000, 2003a & b).

In contrast, a substantial amount of research has found little damage (McCauley et al. 2008) or limited evidence of physical injury in response to seismic exposure (Boeger et al. 2006, Falk and Lawrence 1973, Hassel et al. 2003, Hastings and Miksis-Olds 2012, Holiday et al. 1987, IMG 2002, Koshlevea 1992, McCauley and Kent 2012, Popper et al. 2005 & 2016, Song et al. 2008, Santulli et al 1999, Thomsen 2002, Weinhold and Weaver 1972).

Research examining impacts to physiology have also shown conflicting results with sea bass (*Dicentrarchus labrax*) showing increased serum, cortisol, glucose and lactate after exposure (Santulli et al. 1999) where as a range of Western Australian species showed no measured response (McCauley et al. 2000).

Seismic sound can cause behavioural responses in marine finfish, some of which may negatively affect a population (e.g. reduced rate of foraging or predator avoidance), and others which may pose little increase to risk (e.g. brief startle response) (Carroll et al. 2017). Most studies were based in laboratories or using cages and need to be interpreted with caution. Airgun discharges have been reported to cause a range of startle and alarm responses in fish, including C-starts (an involuntary response where all the lateral muscles along one side of the fish contract and the fish darts off in that direction), changes in schooling patterns, water column positions and swimming speeds (Boeger et al 2006, Chapman and Hawkins 1969, Dalen and Knutsen 1987, Engas et al. 1996, Fewtrell and McCauley 2012, Hassel et al. 2003 & 2004, McCauley et al. 2000 & 2003a & b, Pearson et al. 1992, Przeslawski et al. 2017, Santulli et al. 1999, Skalski et al. 1992, Slotte et al. 2004, Thomsen 2002, Wardle et al. 2001). While some species show strong behavioural changes to seismic sound exposure, a lack of behavioural effects have been observed in other species (Hassel et al. 2003, IMG 2002, Pena et al. 2013, Popper et al. 2005, Wardle et al. 2001). Some fish species have potentially shown habituation to repeated airgun noise, with some fish showing less startle responses or quickly returning to normal behavioural patterns (Boeger et al. 2006, Fewtrell and McCauley 2012, Pearson et al. 1992).

Anthropogenic noise also has the potential to mask biologically relevant acoustic cues, which in turn can affect fish survival (Popper 2009). Acoustic production is an important process during courtship and spawning displays for some species (Hawkins and Amorim 2000, Mann 2016, Moulton 1963), defensive territorial displays (Myrberg 1997, Tricas et al. 2006), intraspecific communication (Riggio 1985), predator avoidance (Anglea et al. 2004, Godin and Morgan 1985) and/or prey detection (Giguère and Dill 1979). Underwater sound is also important for orientation of coastal marine fish species, especially during settlement processes in their pelagic larval stage (Leis et al. 2003, Mann et al. 2007, Simpson et al. 2004, Wright et al. 2005). Anthropogenic noise (mainly boat traffic) has been shown to affect fish communication (Codrain et al. 2009, Vasconcelos et al. 2007), settlement of coral fish larvae (Simpson et al. 2008) and predator detection (Doksaeter et al. 2009, Slabbekoorn, et al. 2010).

4.4 Finfish pelagic (e.g. spanish mackerel, silver trevally)

Table 4-4 Risk scores and risk ratings for pelagic finfish as scored in the workshop

	Air gun array volume (in^3)		
Depth (m)	**<2000**	**2000-4500**	**>4500**
≥ 20	N/A	N/A	N/A
50	N/A	N/A	N/A
100	N/A	N/A	N/A
>250	C2, L1 = 2 (NEGLIGIBLE)	C2, L1 = 2 (NEGLIGIBLE)	C2, L1 = 2 (NEGLIGIBLE)

4.4.1 Risk justification – workshop discussions

Risk scores for pelagic species was based on the impacts of seismic in waters >250 m (Table 4-4), risk scores were not allocated for depths < 250m as it was assumed that pelagic species do not frequently inhabit these depths.

The main assumption made in the workshop in relation to impacts to pelagic species was that whilst pelagic fish do occur in the upper 20m of the water column, they have the potential to swim to deeper water where they are less likely to be impacted by seismic operations. Due to this capacity the impacts to pelagic fish were only scored for the >250m category. The risk to pelagic finfish was rated as negligible for all sound intensities at depths of >250 m. Risk scores were based mainly on research on silver trevally (*Pseudocaranx dentex*) (McCauley et al. 2000). It is recognised that silver trevally is a temperate species which inhabits both inshore and pelagic waters, however, this was the only available research of seismic impacts on a species which inhabits deeper waters. There is currently an absence of information on the impacts of seismic on truly pelagic species such as swordfish and tuna.

4.4.2 Summary of research referred to in workshop discussions

McCauley et al. (2000) undertook extensive research on the effects of seismic sound on 16 species of fish, including one pelagic species, the silver trevally (*Pseudocaranx dentex*) (exposure 156-191 dB re 1 µPa) Impacts of seismic sound to trevally were similar to demersal species and included: startle response, tendency for faster swimming and formation of tight groups, movement to the bottom centre of the cage (see Section 4.3 for a more detailed description) These behaviours became increasing more prevalent as the air-gun threshold increased (Fewtrell and McCauley 2012, McCauley et al. 2000).

4.4.3 "Other" research on seismic impacts to pelagic finfish

The majority of research of impacts of seismic is based on demersal species (Section 4.3), with some experiments on pelagic species.

Pelagic fish including herring (*Clupea harengus*) and blue whiting (*Micromesistius poutassou*) were shown to descend in the water column in response to air gun exposure at between 189 – 197 dB re 1 µPa (Slotte et al. 2004). The same study found that the abundance of pelagic and mesopelagic fish was greater outside than inside the shooting area of seismic surveys. Studies by La Bella et al. (1996) also found a shift in the vertical distribution of pelagic finfish species in response to seismic sound. In contrast to other research, this study found that fish moved in the opposite direction, moving towards the surface layer in response to seismic sound.

5 Summary

Risk scores were allocated based on the collective knowledge and expertise of participants in the workshop. During the workshop risk scores were largely estimated using the results of a few key studies investigating impacts on a limited number of Australian marine species. The workshop highlighted the need for a greater understanding of seismic impacts. The recently announced research initiative on seismic impacts led by the Australian Institute of Marine Science (AIMS) is likely to provide additional valuable information on the effects of seismic surveys on marine organisms. The risk ratings provided in this report will need to be reviewed, once the outcomes of the AIMS research becomes available along with any other new information.

This risk assessment identified that overall the greater the intensity of sound and shallower the water depth the greater the assigned risk. For all fish and invertebrates the impacts of seismic surveys, in waters deeper than 250 m was assessed as acceptable (i.e. moderate or lower). In waters <250m, the scores ranged from negligible to severe risk depending on depth, resource and seismic intensity. The organisms classified as most at risk from seismic impacts were immobile invertebrates (e.g. molluscs) while pelagic fish were rated as at the least at risk (Figure 5-1).

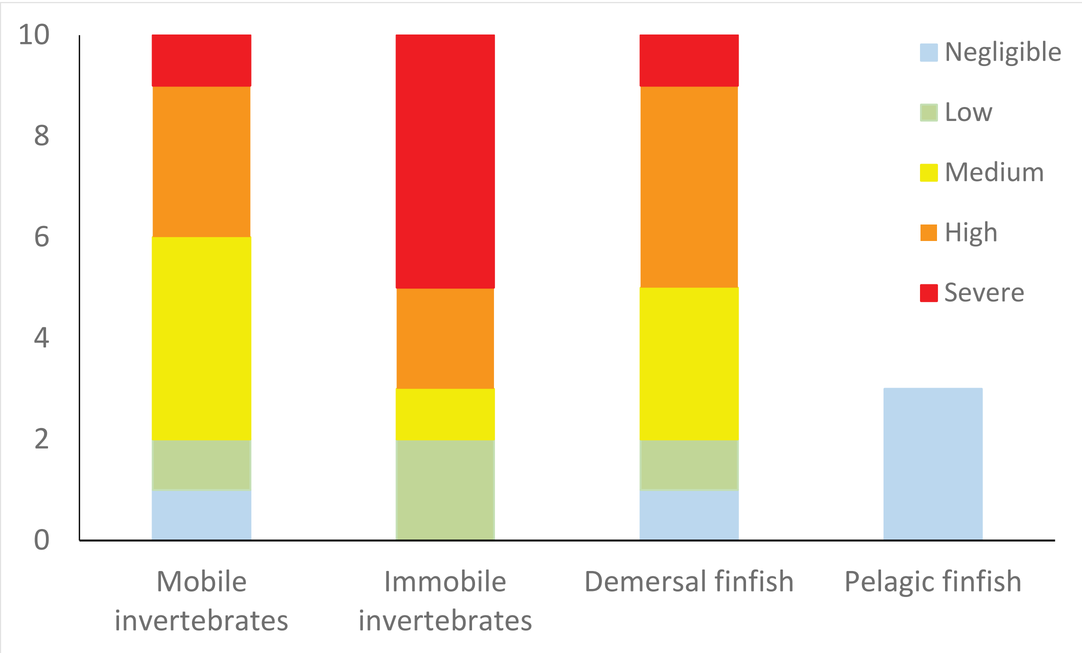

Figure 5-1 Summary of risk scores for aquatic resource type

Mobile invertebrates: Risk ratings for mobile invertebrates were mostly based on studies on the southern rock lobster (*J. edwardsii*). Research has shown behavioural responses with delayed ability of lobsters to right themselves and reduced tail extension, physical effects through damage to the hairs surrounding the statocycst and a range of physiological impacts (Day et al. 2016). These impacts were considered sublethal impacts with the potential to affect reproduction.

Immobile invertebrates: Risk ratings for immobile invertebrates was mainly based on the outcomes of research on the commercial scallop (*P. fumatus*) (Day et al. 2016). Research found that scallops had higher mortality after exposure to seismic surveys with mortality increasing with repeated exposure. This mortality was not immediate but occurred post-exposure, with maximum mortality occurring after 120 days. Physiological impacts were also observed, with significant changes to a range of haemolymph properties. Scallop behaviour was also affected.

Demersal fish: Risk scores were based mainly on caged based research on two commercial species pink snapper (*C. auratus*) and goldband snapper (*P. multidens*) (McCauley and Fewtrall 2008, McCauley and Kent 2012, McCauley 2000, 2003a & b). Research showed that pink snapper had extensive damage to hairs surrounding the statocyst after seismic exposure. While not studied directly these impacts may impact long term survival and reproduction. Seismic sound was found to affect goldband behaviour (startle and alarm response, change in swimming behaviour and vertical position). There were four high risk scores and one severe risk score for demersal species.

Pelagic fish: Due to most pelagic species inhabiting deeper water where seismic impacts are attenuated, the risk scores to pelagic species were scored as negligible. The impacts of seismic to pelagic species were based mainly on research to silver trevally (*P. dentex*) (McCauley et al. 2000).

5.1 Future directions

This risk assessment has examined the impacts of seismic surveys on individual adult marine organisms in terms of effects on survival and reproductive potential. This represents the first step in estimating the broader impacts a seismic survey may pose to species on larger spatial scales, e.g. at the level of species populations, management units and fisheries. A guidance statement is currently being developed by Fisheries which will provide additional information for proponents in this regard. It is anticipated the new guidance statement will be finalised in 2018.

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7 Appendices.

Appendix 1. Workshop participants

Attendees	Representative Body
Facilitators	
Brent Wise	Fisheries Supervising Research Scientist
Rick Fletcher	Fisheries Executive Director Fisheries Research
Participants	
John Harrison	WAFIC Chief Executive Officer
Mannie Shea	WAFIC Executive Officer
Robert McCauley	Curtin University
Euan Harvey	Curtin University
Chandra P. Salgado Kent	Curtin University
Aaron Irving	Pearl Producers Association
Andrew Long	Petroleum Geo-Services
Matt Hatch	Woodside Energy
Libby Howitt	Quadrant Energy
Jayson Semmens	University of Tasmania
Jenny Shaw	Western Australian Marine Science Institution
**Tim Carter and Cameron Sim	National Offshore Petroleum Safety and Environmental Management Authority
Jade Herwig and Stan Bowes	Department of Mines, Industry Regulation and Safety
Mark Meekan	Australian Institute of Marine Science
Tanya Whiteway	Geoscience Australia
Johnathon Davey	Seafood Industry Victoria
John Hughes	International Association of Geophysical Contractors
Brett McCallum	Fisheries Research and Development Corporation
Andrew Rowland	Recfishwest
Shaun Wilson	Department of Biodiversity, Conservation and Attractions
Petrina Raitt	Green Light Environmental, APPEA

Apologies	
Gavin Begg	South Australian Research and Development Institute
James Findlay	Australian Fisheries Management Authority
Beth Gibson	Australian Fisheries Management Authority
Mike Travers	Department of Fisheries
Steven Clarke -	South Australian Research and Development Institute
Andrew Rowland	Recfish West
Ray Masini	Office of the Environmental Protection
Patrick Hone	Fisheries Research and Development Commission
Rachel Przeslawski –	Geoscience Australia
Alex Ogg	WAFIC Operations Manager
Andrew Taylor	Australian Petroleum Production & Exploration Association Limited
Alan Kendrick	Department of Biodiversity, Conservation and Attractions
Nathan Hanna and Kerry Cameron	Department of the Environment and Energy
James Findlay	The Australian Fisheries Management Authority
Gavin Begg	South Australia Research and Development

DPIRD (Fisheries) Attendees (note that Fisheries staff were not involved in the scoring process)	
Rhiannon Jones	Fisheries Management Officer
Carli Telfer	Senior Management Officer
Fiona Webster	Research Scientist
Stephen Newman	Principle Research Scientist
Nick Caputi	Supervising Research Scientist
Brett Molony	Director Aquatic Resource Management
Gary Jackson	Principle Research Scientist
Clint Syers	Principle Policy Manager
Anthony Hart	Principle Research Scientist

** Note that NOPSEMA representatives were present only for the morning session and were deliberately not present for the risk scoring component of the workshop

Appendix 2. Organisations which provided comment on the ERA report

Organisation
Department of Biodiversity, Conservation and Attractions
Western Australian Department of Mines, Industry, Regulation and Safety
International Association of Geophysical Contractors
National Offshore Petroleum Safety and Environmental Management Authority
University of Western Australia Oceans Institute
Curtin University, Centre for Marine Research and Technology
Geoscience Australia
Australian Petroleum Production & Exploration Association Limited