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Review of the potential economic impacts of the development of an offshore oil and gas industry on the Great Australian Bight fishing and aquaculture industry

Final Report GABRP Project 6.3 - PART B

Sean Pascoe and James Innes

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CONTACT

Dr Sean Pascoe
CSIRO
e: sean.pascoe@csiro.au

FOR FURTHER INFORMATION

www.misa.net.au/GAB

GREAT AUSTRALIAN BIGHT RESEARCH PROGRAM

The Great Australian Bight Research Program is a collaboration between BP, CSIRO, the South Australian Research and Development Institute (SARDI), the University of Adelaide, and Flinders University. The Program aims to provide a whole-of-system understanding of the environmental, economic and social values of the region; providing an information source for all to use.

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EXECUTIVE SUMMARY

The study had two main objectives:

- Provide a qualitative assessment of the potential impacts of the development of an oil industry in the Great Australian Bight (GAB) on the fisheries and aquaculture sectors based on a review of impacts experienced elsewhere; and
- Review approaches for undertaking economic impact assessment of the effects of any oil spills on the fisheries in the region.

Review of potential impacts of the development of an oil industry: international experiences

The development of an oil industry may produce a number of benefits for a regional economy, including increased incomes and employment opportunities. Based on a review of similar developments elsewhere, establishing an oil industry may have wide ranging impacts on commercial fishing from both onshore and offshore activities. Onshore activities relate to the development of onshore facilities to support land based operations, store oil, etc., while offshore activities involve the production platforms itself. A summary of these potential impacts is given below.

Onshore impacts experienced elsewhere have been both positive and negative. The development of onshore infrastructure may provide benefits to fisheries such as improved port and handling facilities, lower cost access to inputs and services previously not supplied locally, and improved safety facilities (e.g. search and rescue helicopters). In some cases, however, the provision of alternative employment opportunities in the region may r increase the competition for labour, while higher incomes in the oil sector and an increased population may increase the cost of living in the region, compounding the problem of wage competition if fisheries are unable to compete. Similar pressures have also been experienced in Australia as a result of the recent mining boom, which resulted in the cost of living, particularly housing, increasing substantially in some regional areas, crowding out other sectors as a result.

The review of international experiences has also identified a number of potential offshore related impacts. These include the loss of access to fishing grounds due to exclusion zones around the oil rigs, and perceptions that seismic testing can disturb fish and make them harder to catch. These impacts were generally found to be fairly small, with the exclusion zone around oil production platforms generally not more than 500 m. The exclusion zone around the oil production platforms was believed to have a positive impact on the stocks of some species by acting as a small marine protected area. The sinking of oil production platforms that have reached the end of their productive lives can also generate benefits by creating artificial reefs.

In some studies, concerns were raised around increased vessel traffic in ports and potential implications for safety if fishing vessels have to move through the area. Also associated with the increased vessel traffic is an increased risk of introduction of invasive species. The potential for invasive species introduction, however, is related to increased vessel movements, and is not limited to the development of an oil industry. For example, increased agricultural or mineral trade also increases the risk of invasive species.

The most substantial fisheries economic impacts were observed in relation to oil spills. In most cases, these were the result of oil tanker accidents, often close inshore. In such cases, fisheries impacts were substantial in the short term, mostly as a result of fishery closures which reduced production and market responses which in turn reduced prices. For most fish species, little or no lasting impact on the stocks was observed, and fisheries generally recovered fairly rapidly. For many

shellfish species, such as non-hatchery based oysters, both physical and market recovery took longer. The Deepwater Horizon oil spill in the Gulf of Mexico in 2010 provided an example of the effects of a large scale oil spill from an offshore oil exploration rig. In January 2015, the United States District Court for the Eastern District of Louisiana found that 3.19 million barrels of oil (MMbbl) were discharged into the Gulf of Mexico. Many fisheries were closed for several months, resulting in substantial loss of fishing incomes – ranging from 25% to 60% depending on the study methodology. As above, in most cases these impacts were short lived, with most fish stocks recovering to pre-spill levels fairly rapidly. In some cases, the extended fishery closure was believed to have benefited some stocks.

Qualitative assessment of potential impacts in the GAB

Based on the potential impacts identified in the review, a qualitative assessment was undertaken to determine the extent to which these may affect the fisheries in the GAB. Many of the potentially negative onshore impacts are expected not to have an impact in the GAB, as numerous ports exist along the South Australian coast, exporting agricultural and mineral products. South Australia also has a substantial mining industry, and hence the fisheries have evolved in the presence of strong competition for labour, while regional communities have been faced with the cost of living pressures associated with high incomes in the mining sector. For some fishers, the development of new alternative employment options may provide an opportunity to exit the fishery. However, for many fishers, their attachment to the industry is sufficiently strong that they will not be attracted out of the industry. In any case, any increase in labour demand will most likely be for skills not currently available in the fishing industry.

With the exception of an oil spill, offshore impacts are also likely to be small. Most of the proposed development is a substantial distance from the main fishing activities, while the area lost to fishing for the deeper water vessels is small in comparison to the area available. Increases in vessel traffic are also likely to be small compared with the existing traffic associated with the exports of agricultural and mineral products.

While the likelihood of an oil spill is small, potential economic consequences are potentially considerable. The impact of an oil spill will largely depend on a wide range of factors including when it occurs, the direction and strength of the currents, how far away it is from the fishery, and the sensitivity of the target species and associated habitat to oil. Potentially more significant is the management response in terms of closure, the ability of the vessels to move to alternative fishing grounds, the market response to the spill and the resilience of the industry to short term shocks. Assessing impacts with so many variables is complex without some form of model, and a qualitative Bayesian Belief Network (BBN) model was developed to identify which fisheries, if any, would be most adversely affected. Only a limited number of scenarios and fisheries and aquaculture sectors were considered for the preliminary analysis.

The results suggest that some fisheries, such as the Southern Bluefin Tuna (SBT) fishery, will only experience a small impact. Others, such as the Marine Scalefish fishery, may experience a moderate short term impact, while others still, such as oyster aquaculture, may experience a substantial short term impact, depending on assumptions about how much oil was released and the direction of currents at the time. Medium to longer term impacts were not addressed, although hatchery-based restocking of the oyster industry may negate biophysical impacts of the oil.

Review of approaches to undertaking economic impact assessment of the effects of an oil spill

While compensation will ultimately be based on individual claims, considerable time generally elapses before all claims are settled, and information at the fishery level is often not made available.

Estimating the economic impacts in different fisheries provides a means to rapidly assess priorities for fisheries support following such an event.

To this end, the study reviewed previous approaches to estimate fishery economic impacts ex post to determine which may be most appropriate if ever needed in the GAB. The review focused on both theoretical methods proposed for assessing oil spill impacts, as well as reviews of estimates of such impacts using a range of methods. A variety of approaches have been used and/or proposed, ranging from complex modelling based methods to simple comparisons of values before and after the event.

In many cases, the estimate of the cost to the fishery was method and assumption dependent. Given that compensation claims are most commonly based on individual loss of fisheries profits, supported by a comparison of profits during the impacted period (usually the year in which the spill occurs) with information on profits, catches, prices and costs over the preceding three years, it is suggested that a similar approach be adopted for ex post evaluation of potential costs. Such an approach is imperfect as it does not take into account longer term impacts, although to capture these some form of detailed bioeconomic model would be required which encompasses fleet behaviour, market behaviour and biological responses to the oil spill. Such a model would be dependent on the existence of information that is generally not available until after the event (e.g. identifying fish stock responses to the oil spill, and subsequent behavioural responses by the fishers and market responses will not be known with certainty until after they have been observed). While assumptions about these relationships can be made, results are sensitive to the assumptions and may be no more accurate than those generated by the simple approach with known deficiencies.

Even the simple approach requires information on previous catch, effort, price and cost information on the fisheries. A major difficulty identified in the review of past spills was the lack of appropriate data to estimate the impacts. South Australian commercial fisheries are fortunate in that detailed economic data have been collected for some time. For aquaculture, which may also be adversely affected, data are less publicly available, particularly on cost structures and profitability – both essential factors for determining any economic impacts.

The potential impact of any oil spill on markets is also poorly understood. From the qualitative analysis undertaken using the BBN, most commercial fisheries profits were sensitive to changes in price. For aquaculture, particularly the molluscs which are filter feeders, a potential pollution event such as an oil spill may have a substantial impact on the price received.

INTRODUCTION

Overview

The Great Australian Bight (GAB) supports a wide range of commercial and recreational activities including fisheries (both recreational and commercial) and tourism, as well as providing habitat for a range of iconic marine mammals (e.g. seals and whales).

Over the last five years, there has been increasing interest in the potential for the development of an oil and gas industry in the GAB. In January 2011, BP was awarded four exploration permits about 300 km south-west of Ceduna and committed to a work program that includes drilling four exploration wells. In 2011, Bight Petroleum was also awarded two leases west of Kangaroo Island and south of the Eyre Peninsula. In 2013, Statoil acquired a 30% share in BPs exploration program; Chevron was awarded two permits east of the BP/Statoil leases; and Santos/Murphy was awarded a lease further west (Figure 1). While BP and Chevron have subsequently decided not to proceed with drilling, other oil-related developments may still take place in the region.

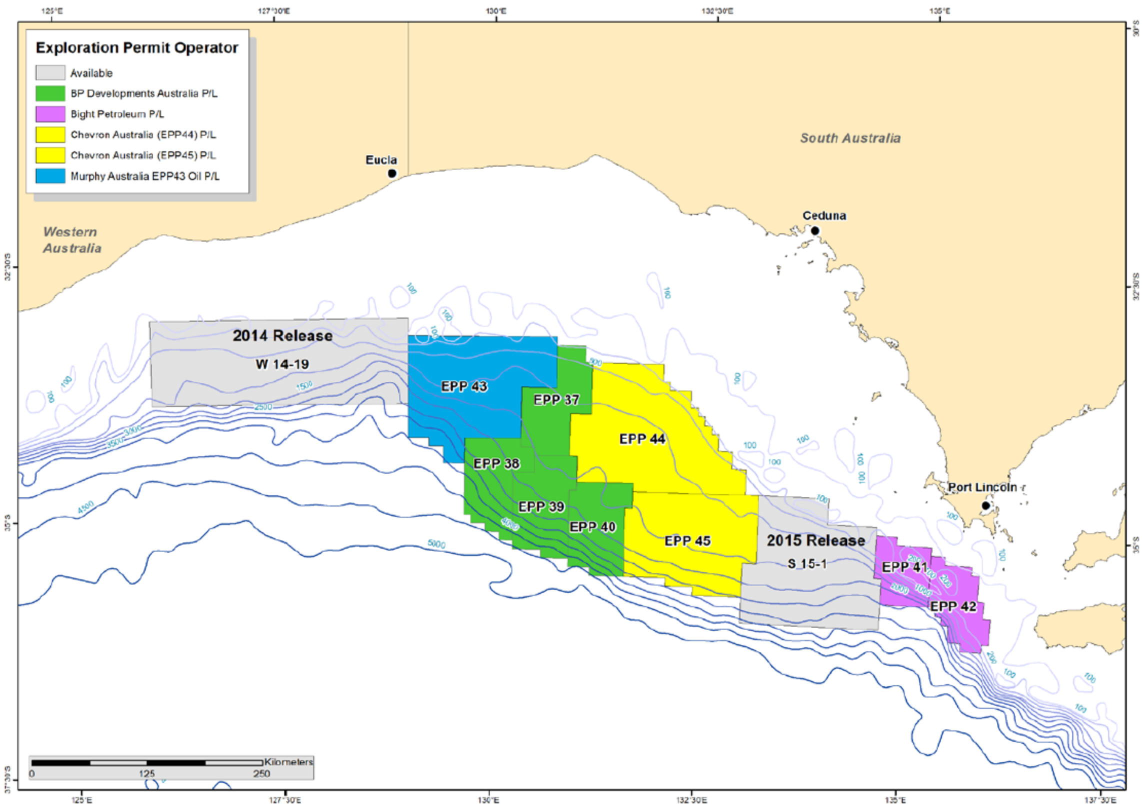

Figure 1. Oil exploration permit areas, GAB

Source: BP Developments Australia Pty Ltd (2015b)

This study is part of a broader GAB Research Program focusing on collating information about the marine resources of the Great Australian Bight and providing vital knowledge necessary to support future decisions for sustainable development in the region. The focus of this study is to review the experiences elsewhere with fishery-oil development interactions, as well as the methodologies used elsewhere to estimate economic impacts of oil spills on fisheries and the marine environment. In the

light of these experiences, potential impact types of development of an oil and gas industry on GAB fisheries are discussed qualitatively.

Background and Need

The GAB has substantial fisheries resources that form the basis of a number of State and Commonwealth managed fisheries. South Australia is the second largest Australian producer of wild caught fish by value (after Western Australia) from State fisheries, and the second largest aquaculture producer by value (after Tasmania) (ABARES 2015). Total value of SA fisheries production averages $400m a year, split equally between wild caught fisheries and aquaculture, and directly employs almost 2000 full time equivalent positions. Two major Commonwealth managed fisheries (Southern Bluefin Tuna (SBT) and the Southern and Eastern Scalefish and Shark Fishery) also operate in the GAB, with a combined value of around $60m a year. While small relative to the total State gross domestic product, commercial fishing is a major component of many regional economies, especially those away from the main metropolitan regions, contributing as much as 14% of gross value of production in some regions (EconSearch 2012). A full review of these fisheries has been undertaken in a separate study, which provides a baseline describing the economic and social performance of the GAB fisheries (Pascoe and Innes 2017).

Experiences elsewhere suggest that the development of an offshore oil and gas industry in the GAB could have both positive and negative influences on the fishing industry. Most retrospective analyses have focused on negative influences, such as changes in total landings before and after an incident (e.g. Garza-Gil *et al.* 2006a; Lorenzen *et al.* 2006), but others suggest that factors such as price changes and location choice (e.g. Collins *et al.* 2003; García Negro *et al.* 2009) are also highly influential in mitigating some potential negative impacts. Social impacts, which are more likely to occur onshore in coastal communities, have rarely been considered (Palinkas *et al.* 1993; O'Rourke and Connolly 2003).

Methods for assessing social and economic impacts on fisheries and aquaculture from non-fishing oceanic activities are generally poorly developed in Australia. The aim of this study was to review previous international studies which documented oil-fisheries interactions, and the methods used to assess any impacts on fisheries and the marine environment. From this, a qualitative assessment of the types of fisheries (including both wild caught and aquaculture industries) impacts that may be experienced in the GAB is presented.

The study is limited to fisheries and marine environment related impacts. The development of an oil industry can have both social and economic impacts on-shore in coastal communities – both positive, such as employment, and negative – as well as to the larger community through tax receipts, royalties and energy security. The onshore social and economic impacts of the development of the oil industry in the GAB are the topic of separate projects, and are reported in Beer and Thredgold (2017) and O'Neil *et al.* (2017).

Objectives

The study had two main objectives:

1. Provide a qualitative assessment of the potential impacts of the development of an oil industry in the Great Australian Bight (GAB) on the fisheries and aquaculture sectors based on a review of impacts experienced elsewhere; and
2. Review approaches for undertaking economic impact assessment of the effects of any oil spills on the fisheries in the region.

METHODS OVERVIEW

The study was desk based, involving a review of the existing peer-reviewed literature of oil-fishery interactions. The review was organised in terms of the key impacts identified in the literature for a range of different fisheries worldwide.

From this, a qualitative assessment of the potential implications of such interactions in the GAB was undertaken, drawing on experiences elsewhere in which oil and gas developments have had an impact on fishing (or other similar) industries. Key issues considered were the potential changes in local market conditions (which may benefit fisheries), increased competition for key inputs (such as labour) through the additional demand created by the new developments, and potential impacts from oil spills.

Existing literature assessing impacts of oil spills (mainly from tanker accidents) was also reviewed. The review focused on the types of impacts on fisheries previously identified and the methods used to assess them. The potential for proactive management responses to mitigate these impacts was also considered, although these were not common in the existing literature.

Based on the review of oil spill impacts, a Bayesian Belief Network (BBN) model was developed to assess the potential impacts of an oil spill on fisheries and aquaculture in the GAB. BBNs are largely qualitative models that do not model process, but rather expected probabilities of outcomes given particular combinations of events. Full details of the models developed are presented in Section 4.1.6 and Appendix A and B. The BBNs were used to assess the likely relative economic impacts of different hypothetical oil spill scenarios (i.e. duration, timing etc.) on the key fisheries and aquaculture industries likely to be affected.

RESULTS

Given the increasing demand for oil across the globe and the declining oil reserves in the more readily accessible terrestrial environment, there is a growing interest in the extraction of these resources offshore. Over the last few decades, the offshore oil and gas industry has expanded globally, with around one third of oil and gas extracted worldwide now coming from offshore sources (World Ocean Review 2014) with an approximate value of US$1.7 trillion in 2014. Australia is currently the third largest exporter of liquid natural gas (APPEA 2015), with over 90% of the gas resources lying in offshore basins, most of which are yet to be exploited.

In Australia, the oil and gas industry produces over $20 billion worth of material a year, with the potential to increase threefold within the next decade (Oceans Policy Science Advisory Group 2013). In 2013, over 22,000 full time equivalent workers were employed directly in the sector, with an additional 65,000 full time equivalent positions in associated contract work (APPEA 2014a). The industry as a whole has contributed roughly $8 billion a year to the broader community through taxation over the last five years (APPEA 2015).

While the potential developments in the GAB are largely based offshore in terms of their physical operations, many of the economic benefits will be experienced onshore. In particular, associated employment and infrastructure development onshore will result in flow on effects to the regional economies in which they are based. Similarly, increased tax revenues and royalty payments generated through the operation will benefit the broader community.

Potential onshore benefits of the development of an oil and gas industry in the GAB are being examined elsewhere (Beer and Thredgold 2017; O'Neil et al. 2017). The focus of this section is on potential interactions with the fishing industry.

International review of the impacts of the development of an oil industry on fishing industries

Increasingly, the marine environment is being used for the development of renewable and non-renewable energy-based industries, which can potentially impinge on fishing activities either directly (through displacement) or indirectly (through unintended consequences such as spills). A key aim of the study was to review impacts on fisheries associated with the development of oil industries elsewhere.

Based on this review, the potential impacts of offshore oil and gas development can be broadly broken down into two groups, depending upon whether they eventuate from activities onshore or offshore.

Onshore-based interactions

Onshore interactions are those that arise from onshore based activities associated with the development of an offshore oil industry which may have implications for the operation of fisheries or their economic performance. These include the development of onshore infrastructure to support the industry, as well as income related impacts arising from improved employment opportunities.

Relatively few studies have been undertaken previously looking at these issues, suggesting that in many cases these impacts are not substantial for fisheries (although may have wider implications for the regional economy as a whole). The existing studies are summarised below. Implications for the GAB fisheries will be discussed in the following sections.

Onshore infrastructure development

The development of offshore structures also requires additional onshore infrastructure to service them. Onshore infrastructure related to offshore oil production often includes improved transport systems, helipads, supply bases and port development (Dismukes 2014). As well as creating onshore economic benefits to the broader community, the development of such accompanying infrastructure can provide direct and indirect benefits to the fishing industry, through providing better links with the market and for the supply of fishing inputs, as well as access to improved port facilities where these are also developed. Triantafillos *et al.* (2014) identified lack of appropriate infrastructure as a major concern for both recreational and commercial fishing in South Australia.

Competition for labour due to alternative employment opportunities

Fishers are often located in relatively remote locations, with relatively few alternative employment opportunities. Oil related employment opportunities that offer higher wages than the fishing industry can lead to a situation in which fisheries struggle to retain or find good crew. This is not necessarily an issue with oil development *per se*, and has also been seen during the expansion of the onshore mining industry. Further, the increased demand for labour services in other sectors can also impinge on costs to fishers (e.g. mechanics, engineers, etc.).

For example, the Great Barrier Reef Coral Reef Fin-Fish Fishery (CRFFF) which operates out of ports on Queensland's east coast is in an area with (previously) high levels of land based mining activities. A common complaint of vessel skippers and owners was that they could not compete with the mines for crew and that, in a number of areas, the cost of moorings and other port services (e.g. engineers, refrigeration specialists) had greatly increased as a result of increased demand from mining activity (Thébaud *et al.* 2014). Similar claims have been made in other Queensland based fisheries during the mining boom.

A study undertaken to assess the potential impacts of a proposed LNG development at James Price Point (JPP) in Australia's Kimberly region found there was likely to be a decline in most commercial fisheries as a result of the development. This was predicted to occur due to both environmental factors and competition for the supply of port services which would have flow on effects to the local economy (Wright and Pyke 2010). However, associated upgrades to facilities at the Port of Broome that were predicted to come about as a direct result of the same development were viewed as a positive outcome by the commercial and recreational fishing industry (Wright and Pyke 2010). The actual outcome is unknown, as the development has not proceeded.

The provision of alternative employment opportunities, while potentially increasing the cost of labour and services to the industry, can also provide benefits. As might be expected, case specific factors such as the relative contribution of the fishing industry to the local labour market and the relative financial performance of the separate industries are important determinants of whether the fishing industry will be positively or negatively affected. Fisheries that are performing poorly can potentially benefit through effort reduction arising from the generation of alternative employment opportunities. Pascoe *et al.* (2015) found that satisfaction with income was a major determinant of overall satisfaction with the industry, which in turn was the major determinant of a fisher's willingness to leave the industry if an alternative opportunity was presented. Stead (2005) also found that the migration of skilled labour from the fishing to oil industry was more a result of the poor economic performance of fisheries in Scotland's North East region – a "push" from fishing more than a "pull" from oil. In both cases, reduced excess capacity in the fishery can result in an improvement in the overall economic performance of the industry.

The offshore oil and gas industry can also generate opportunities for fishers to supplement their income through diversification. In the Gulf of Mexico, owners of local shrimp vessels were able to capitalise on an initial shortage of vessels to transport supplies to production platforms and aid with navigation (Austin *et al.* 2002; Gramling and Freudenburg 2006). The scheduling of offshore oil work (7, 14 or 21 day cycles with the same period of off-time) is also reported to have helped the oil and fishing industries coexist more harmoniously by allowing workers to maintain traditional coastal occupations such as fishing whilst also working on offshore oil fields (Gramling and Freudenburg 2006). This meant that in periods when there were fewer oil related employment opportunities, or when extraction ceased in an area, individuals still had their ongoing fishing opportunities to fall back on (Austin *et al*. 2002).

The potential impacts of increased demand for labour can be mitigated through effective management of the process. When the North Sea oil fields were developed, specific policies directly aimed at ensuring the preservation and maintenance of their traditional industries were put in place by communities in the Shetland Islands. They were enacted with the explicit goal of ensuring that the traditional industries would remain once the opportunities provided by oil were gone. Despite this, overall employment in fishing (catching, processing and ancillary combined) was seen to fall 24% over the period assessed (1971-1991). The reduction in employment was attributed to the combined impact of oil-related employment opportunities, over-harvesting, the quality of the fishing environment, and increasing mechanisation (Hill *et al.* 1998). However, it is believed that the reductions in fisheries employment that came about as a result of the oil industry would likely have been worse had the Shetlands not enacted specific policies to limit the impacts (Hill *et al*. 1998).

Inflationary impacts on the local economy

Experiences with the Australian coal mining boom in Queensland have suggested that higher incomes generated in regional economies from the higher wages generally paid by the mining industry can lead to a broader inflationary effect on the cost of living, particularly with respect to housing and a lesser degree food (Rolfe *et al.* 2007). Similar experiences have been seen in Western Australia, with average incomes in Dampier being the highest in the State following the development of mining in the region (Brueckner *et al.* 2014). Housing and the general costs of living have correspondingly increased in these areas, as higher incomes and increased demand for housing in particular forced rental and sale prices up (Brueckner *et al*. 2014).

This can affect the fishing industry directly through higher input prices, and indirectly again through increasing the minimum wage required by labour to continue living in the area. For example, crew will require a higher payment to offset the higher costs of remaining in the region even in the absence of direct competition for labour with the oil industry.

Relatively few studies have examined these impacts on the fishing industry in particular. The inflationary effects of offshore oil development were seen to occur in Stavanger (Norway) and Aberdeen (Scotland) in the form of increased prices for property and land, and wage increases in trades such as welding (Voyer 1983). These were seen to impact the commercial fisheries at the port of Peterhead (Aberdeen area), putting additional financial pressure on fisheries which were already in decline as a result of other external forces affecting fisheries (Crow and Allan 2014).

Offshore impacts

Offshore oil and gas production involves the construction of a physical structure in the ocean which creates a potential source of conflict with the fisheries operating in the area. These include the

potential loss of fishing area, as well as possible influences on the fish stocks during the production process.

The impacts that have been experienced elsewhere are identified below. The likelihood of these impacts affecting GAB fisheries are discussed in the following section.

Area restrictions

Offshore oil production platforms generally have a safety exclusion zone that extends up to 500 m around their periphery, largely to protect the structures from collisions with vessels (Kashubsky and Morrison 2013; NOPSEMA 2015), restricting access of other vessels to an area of approximately 0.8 km^2 around each structure. In isolation, the loss of potential fishing area from an individual production platform is small. However, where multiple production platforms are in place, the loss of fishing area may be substantial. This can lead to greater levels of fishing effort in areas that remain accessible, which in turn may lead to crowding and localised depletion. The significance of these impacts from a fisheries perspective depends on factors such as the mobility of target species and how much of the fishing area is lost.

In some areas of the world, the economic impact of loss of fishing access due to the development of an offshore oil industry has been substantial. MacKay Consultants (1987) estimated that approximately 308 square miles of UK continental shelf had been lost to fishing as a result of oil and gas developments, equating to a monetary loss of £275,000-3,000,000 in 1986 (~£0.5-6 million in 2014 values). Loss of access to fishing grounds and damage to gear are also reported to have been a source of conflict between the fisheries and offshore petroleum industry in Lake Erie in the US (Val and Nelson 1983). A study considering the potential effects of offshore oil and gas development on Georges Bank reported that reduced access to previously fished areas had the potential to result in reductions in efficiency (due to crowding) and economic losses in existing scallop, lobster and swordfish fisheries (OEER 2010). In the latter case, the fishing industry also raised concerns that oil and gas infrastructure could potentially alter the migration patterns of pelagic species resulting in decreased landings and value of production, increased costs of production for vessels, and ultimately lower levels of employment in the fishing industry (OEER 2010).

The creation of what are effectively no-take zones around the oil production platforms can potentially have some benefits to the fishing industry also, as the structures themselves can provide a valuable fisheries habitat. Claisse *et al*. (2014) found that the fish communities living on the complex hardscape habitat created by the physical structure of the oil and gas platforms off California had the highest secondary production per unit area of seafloor of any marine ecosystem for which similar estimates exist, about an order of magnitude higher than fish communities from other marine ecosystems. The extent to which these effects spill over into the commercial fisheries is unknown, and will also depend on the overall size of the restricted area and the degree of connectivity between them. In the Gulf of Mexico, recreational and some commercial fishers were found to have benefited from the artificial reef effect of infrastructure associated with oil and gas extraction; however demersal trawl fisheries were negatively impacted by the combined effect of loss of fishing grounds and compensatory spill over from the closed area (Stanley and Wilson 1990).

Increased vessel traffic

Increased vessel activity, both in port and further offshore, is also often cited as a concern for both industries due to the greater likelihood of collision and potential for it to interfere with their day to day activities (e.g. Kahoe 1993; Glazier *et al.* 2006). Marine aquaculture producers have also raised concerns around the potential for increased vessel activity to damage their infrastructure (Wright and Pyke 2010). Such increased traffic can take place during the exploration phase, as well as the

construction on ongoing production phases. For example, Continental Shelf Associates (2002) have reported that a range of fishing vessels came into conflict with seismic operations in Newfoundland, while Kahoe (1993) reported conflicts arising over delays in getting in and out of port, refuelling and unloading due to increased congestion.

To address this problem, solutions such as dedicated vessel traffic corridors can be established for oil and gas industry vessels, with the specific aim of limiting interaction with fishing vessels (Continental Shelf Associates 2002). However, while these measures may reduce the chances of collisions and other conflicts, they also represent additional limitations on where fishing vessels may operate and a potential loss of fishable grounds, especially if they transect areas and interfere with, for example, established trawl paths or other fishing grounds. Glazier *et al*. (2006) suggests that many of these conflicts can be overcome with continuing dialog between the oil and fishing industry.

A rise in the number of vessels frequenting an area can also increase the risk of non-native, invasive species, being introduced (Goggin 2004). Studies elsewhere have identified drill ships and platforms as being efficient vectors for species introduction (Page *et al.* 2006), while some studies have found a higher proportion of exotic species on oil platforms and drill ships than on cargo ships in general (Ferreira *et al.* 2006). The long term impacts of such an event are difficult to predict in advance as it will largely depend on the species, its ability to survive in the new environment and also how it integrates with the new ecosystem. Some species will have the potential to detrimentally impact the local ecosystem and commercial and recreational fisheries as a consequence. This concern was also raised by the aquaculture industry under the proposed JPP LNG development (Wright and Pyke 2010). Non-native introductions to Australia, such as the northern Pacific seastar, are believed to have originated from ship ballast water and poses a threat to commercial shellfish industries (Goggin 2004).

Debris and navigational hazards

Debris and infrastructure (e.g. underwater pipelines, wellheads, cuttings piles) which have the potential to create navigational hazards or damage fishing gear, are additional concerns for the fishing industry. Their precise impacts are dependent upon the nature of the infrastructure or debris but the risks they pose have resulted in the oil industry contributing to the cost of research assessing the danger unburied pipelines pose to demersal gears, navigational warning systems (e.g. FishSAFE[1]), and funding to compensate for non-attributable losses. Continued claims relating to fishing gear losses (particularly for demersal gears) in the Gulf of Mexico (GoM), Santa Barbara Channel/Santa Maria Basin, and the North Sea suggest that oil/gas industry associated losses are an enduring problem in these regions (Continental Shelf Associates 2002). Since 1989, Oil and Gas UK (OGUK) have recorded approximately 1,500 incidents of damage to gear or vessels, with around 450 of these having occurred since the year 2000 (European Parliament 2013). Pelagic fisheries in the GoM are also reported to have lost or had longline gear damaged as a result of interactions with geophysical survey vessels (Continental Shelf Associates 2002).

Concerns that seismic testing can disturb fish and make them harder to catch

Concerns that seismic testing can disturb target species, making them harder to catch, are also commonly cited and could have implications for vessel revenues. Several studies have suggested that, depending on the species and method of capture, finfish catches may either increase or decrease as a result of changes in fish behaviour due to seismic surveys (Løkkeborg 1991; Engås *et al.* 1993; Løkkeborg and Soldal 1993; Engås *et al.* 1996; Løkkeborg *et al.* 2012). An experimental work program

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[1] FishSAFE is a navigational aid for the North Sea that provides fishing vessel skippers with data on potential hazards. Navigational technology using this data also has the ability to warn a vessel if it is within close proximity to a known subsea obstruction http://www.fishsafe.eu.

in Australia into the impacts of air gun noise on a variety of taxa and species determined that both finfish and squid displayed signs of alarm and changes in swimming behaviour and that this was likely to occur as far as 2-5 km from the source of noise (McCauley 2000). However, this did not cause any long term behavioural changes.

In contrast, behavioural and physiological changes have been observed for rock lobster and scallops (Day *et al.* 2016). Air gun noise testing resulted in loss of tail extension and damage to statocysts (fluid-filled sacs involved in controlling body position and righting response), both of which may affect the ability of the animals to avoid predation and compete for food for several weeks after the impact. Righting reflexes were also impaired in scallops following air gun noise testing, which may also reduce its ability to avoid predation, while increased frequency of exposure was related to an increased rate of recessing into the sediment. Direct mortality, however was not observed for either species, and the implications on these impacts of commercial harvesting is also unclear (Day *et al.* 2016).

Seismic testing occurs over relatively short periods of time and any impacts would potentially be transient. Hirst and Rodhouse (2000) reviewed a range of studies, and found that the impact on catch rates varied substantially between species. For some species (mainly teleost fish species), catch rates declined by between 50 and 70 per cent but only for a short period following the seismic testing (around 5 days). For other species (mainly crustaceans and molluscs, including squid), seismic testing had no noticeable effect on catch rates (Hirst and Rodhouse 2000). Seismic surveys were also not found to significantly affect catch rates of rock lobsters in western Victoria, Australia (Parry and Gason 2006). Similarly, an analysis of seismic surveys and commercial catch rates for finfish in the Bass Strait and Gippsland Basin region found no clear or consistent negative relationship (Thomson *et al.* 2014), while a study in north Western Australia found that seismic surveys had no impact on species abundance or richness (Miller and Cripps 2013).

Studies elsewhere have found negligible impacts on key fish and shellfish species. For example, a study assessing the effects of seismic testing on scallops found no significant effect on mortality, while research assessing the potential effects of pipeline noise on lobster and snow crab fisheries in Nova Scotia found no discernible differences in catch rates (EssoNorgeAS 2004). Experimental work found that seismic air guns had little effect on the behaviour of the fish and invertebrates studied in Scotland (Wardle *et al.* 2001), or shrimp catches in Northeastern Brazil (Andriguetto-Filho *et al.* 2005).

Produced formation water discharges

Water commonly exists within the oil and gas reserves, and the extraction of the oil results in a quantity of water produced as a byproduct. This water may be either discharged, or used as part of the extraction process (e.g. re-pumped back into the well as part of the extraction process). The produced formation water may contain hydrocarbons and other chemicals, potentially including heavy metals in trace levels.

Experiences elsewhere suggest that any potential impacts may be extremely localised, limited to within a few tens of metres from the discharge site due to rapid dilution within the ocean (Somerville *et al.* 1987; Stephens *et al.* 2000). Samples of commercial fish species taken within the vicinity of two offshore oil sites in Canada found no evidence of the chemicals in the produced water that was discharged (Mathieu *et al.* 2011). Similarly, experimental prolonged exposure of juvenile cod and other commercial fish species to diluted produced water found no impact on growth or mortality rates (Burridge *et al.* 2011; Gagnon 2011). However, fish subject to prolonged continuous exposure (in experimental conditions) to even low concentrations of produced water were found to have lower immunity than fish not exposed (Hamoutene *et al.* 2011)

Studies in Australia have been limited. Several studies have identified physiological responses in fish exposed to produced water (King *et al.* 2011), namely a result of the natural detoxification process, but have not extrapolated these results to implications for the fish stock (or survival of the affected fish). In Bass Strait, produced formation water provides the natural water drive for all production fields. However, discharge of this water has been found to have a negligible impact on marine life in Bass Strait, although the potential for bioaccumulation exists (Lavering 1994; Terrens and Tait 1996). These studies concluded that there is very low risk to marine organisms, and any effects will be localised and short-term, and not detrimental to the fisheries of Bass Strait (Lavering 1994; Terrens and Tait 1996).

Rigs to reefs

During their productive life, offshore oil production platforms act as small scale marine protected areas, with the physical structure also providing similar benefits to artificial reefs. As the production platforms reach the end of their productive life, they may also offer potentially greater benefits through their sinking by providing a greater area of artificial reef.

Substantial benefits to commercial and recreational fishers have been claimed in the Gulf of Mexico through the use of production platforms as artificial reefs (Dauterive 2000). In the North Sea, decommissioned oil production platforms have been found to act as sanctuaries to relatively high densities of commercial species such as cod, saithe and mackerel (Soldal *et al.* 2002), while Cripps and Aabel (2002) identified a range of conservation as well as fisheries benefits, with their relative magnitude depending on where the reefs were placed. In the latter case, use of the artificial reefs for conservation purposes outweighed potential fishery benefits, although the differences between the options were not found to be substantial. In contrast, Sayer and Baine (2002) suggest that the potential fisheries benefits of a rigs to reef program in the North Sea are overstated, as only around 1.3% of the saithe stock and around 0.25% of the cod stock are associated with oil and gas platforms, while a substantially greater proportion of the stock would need protecting to provide fisheries benefits.

The potential for recreational benefits in the deeper waters is limited, but there still may be biodiversity and conservation benefits. Natural deep water reefs are rare, but support a wide range of species. A small number of artificial reefs can potentially have a substantial impact on biodiversity (Macreadie *et al.* 2011), which in turn may enhance fisheries production in the region. These potential benefits need to be balanced against potential damage due to relocation of the platforms and contamination.

The creation of artificial reefs, while having conservation benefits, may not necessarily produce fisheries benefits. Californian fishers are opposed to the use of decommissioned oil production platforms for artificial reefs as they perceive the potential fisheries benefits to be less than the cost associated with the continued loss of fishing area (Frumkes 2002).

Other impacts

The potential for indirect impacts on data collection for research, e.g. impacts on long term surveys used to build fish population models that underpin management, has been raised by the Australian Fisheries Management Authority (AFMA). This may be through loss of access to key sample sites, or changes in the local abundance distribution in other areas that affect the reliability of stock assessment models.

There are also some potentially positive externalities of oil and gas investment from a fisheries perspective. For example, the development results in greater provision of safety services in the region

(e.g. helicopter search and rescue capability) or the improvement of port or local market facilities. LNG developments in waters off Massachusetts funded improvements in Boston harbour, in addition to whale monitoring systems for research and the buyout of fishing licenses for fishers wishing to exit the fishery (Perry *et al.* 2012). The development of Aberdeen harbour into a non-tidal 24 hour access port that still accommodates the fishing industry has been attributed to investment by offshore oil and gas developers (Stuffmann *et al.* 1990). The fisheries enhancement fund in Santa Barbra County is paid for by the offshore oil and gas industry to help mitigate their impacts on the local fishing industry and has funded a wide range of research and other activities.

Oil spills

While the occurrence of oil spills from all sources has declined substantially over the last three to four decades (Anderson and LaBelle 2000), when they do occur their impact can be substantial for the fishing industry, the local community and the oil industry itself. The recent Deepwater Horizon spill in the Gulf of Mexico is a prime example of the potential impact such an accident may have on the environment, community and fishing industry (Upton 2011). In January 2015, the United States District Court for the Eastern District of Louisiana found that 3.19 million barrels of oil (MMbbl) were discharged into the Gulf of Mexico. Consequently, there is general concern from the fishing industry about potential impacts, and at the same time, strong incentive for the oil industry to ensure that these impacts do not occur.

Globally, an estimated 1.3 million tonnes of oil enter the marine environment on average each year (National Research Council 2003). While the exact figures varies substantially from year to year, on average the greatest single source of oil in the marine environment is natural seepage (46%), while the greatest anthropogenic sources of marine oil pollution are generally believed to be from land based runoff and intentional discharges from vessels at sea (~37%). In contrast, accidental spills during the production and transportation of oil are believed to be substantially smaller in terms of total volumes released (~17%) (National Research Council 2003).

In Australia, natural seepage is believed to be substantially lower than the global average (Logan *et al.* 2010), representing less than 10% of the oil entering the marine environment. However, localised seepage can be substantial, with estimates that some natural slicks in the Great Australian Bight are up to 1,200 metres long and between 30 and 150 metres wide, occurring in water depths from 5,000 to less than 200 metres (Logan *et al*. 2010). However, the bulk of oil entering the marine environment is still believed to come from land based runoff and unintentional discharges from vessels. Oil industry related discharges (tanker accidents and offshore oil extraction) are believed to contribute around 14% to the annual average release of oil into the marine environment.[2] The number of reported oil spills in Australian waters has roughly halved since the turn of the century, falling from 353 in 1998-99 to 140 in 2008-09 (ABS 2010). The total quantity of oil released into the marine environment in Australia is unknown, as there are oil spills that go unreported (ABS 2010). This follows the international trend, where the number of oil spills globally has decreased from 60-120 a year in the 1970s to less than 5 a year over the last decade, while the average size of each spill has also declined substantially (Kontovas *et al.* 2010).

The development and operation of an offshore oil industry can result in oil being released into the marine environment in a number of different ways:

- oil rig/platform accidents (e.g. blowouts, explosions, structural failure)
- during transportation (e.g. tanker accidents)

[2] http://oils.gpa.unep.org/facts/sources.htm#APPEA

- pipeline breakages
- unintentional discharges of oil from platforms or support vessels

Spills that occur when oil is being transported in tankers often take place relatively close to shore and ends up polluting inshore areas and the coastline as a consequence. As this is where human activity in the marine environment is greatest they are often highly visible and can have substantial impacts on the affected coastal communities. Globally, over 10,000 accidental spillages have been recorded by the International Tanker Owners Pollution Databank (ITOPF) since records began in 1970. Most recorded vessel spills (81%) are relatively small (<7 tonnes) and the number of large spills has been falling over time (ITOPF 2015). Whilst vessels are required to maintain private insurance against the liability of costs associated with spills, the majority of oil producers also contribute to an international fund established to provide compensation for accidental oil spills from tankers.

Increasingly it has become more economically viable to exploit deeper and harder to access offshore oil reserves, and this has led to some oil spills from the drilling operations. Events such as the Deepwater Horizon accident in the Gulf of Mexico (considered the largest offshore oil spill in the industry's history) have increased the focus on the risks associated with deep water drilling platforms (Upton 2011). In Australia, the 2009 Montara oil spill in the Timor Sea off Australia's northwest coastline released an estimated 400 barrels of oil per day into the Timor Sea for approximately 10 weeks. The oil, and dispersant used on the spill, potentially affected marine flora and fauna over a 100,000 km^2 area (Young *et al.* 2011).

Oil spills can have a substantial impact on the fishing industry. For example, the 2010 Deepwater Horizon spill caused significant economic harm to the Gulf fishing industry as a result of fishery closures and consumer concerns around the safety of seafood from the Gulf (Upton 2011). Oil spills generally have at least some level of short term negative impact on the environment, the magnitude of which being dependent on factors such as size, location and the weather at the time they occur and afterwards. Commercial fisheries, aquaculture facilities, recreational fishers, tourism, human health, and ultimately the economies and communities that depend on all of these can be detrimentally affected as a result. In the short term commercial fishery catches may be reduced, costs may increase, or both, if areas are closed and they either cannot access the resource or have to travel further to do so. All of these situations have the potential to negatively impact profits, and having to travel further may introduce additional risk of accidents. Target species may also move out of an area, rendering them inaccessible to the fishery, or can be harmed or killed as a consequence of the potentially toxic effects of the oil. The latter of these two impacts is especially likely if the species of concern are immobile or slow moving demersal species. All of these impacts can impose both short and longer term costs.

Aquaculture businesses may be similarly impacted if an oil spill results in increased levels of mortality or prohibitions on the sale of their products due to concerns over public health. Both industries can additionally be impacted by damage to or loss of fishing equipment or infrastructure used in the production process. Negative publicity and reputation loss that oil spills can generate on the image of their products could also potentially reduce demand for the products, with subsequent reductions in price received.

For example, after the *Braer* grounding in 1993, which released 83,000 tonnes of oil into the marine environment around the Shetland islands: 10% of demersal fishing grounds were negatively affected within 4 months; 40% of shellfish grounds were closed to fishing for 2 years; 25% of all Shetland's farmed salmon was severely tainted, and; an expensive marketing campaign had to be undertaken to mitigate the impact of bad publicity on demand and access to markets (Goodlad 1996; European

Parliament 2013). Longer term impacts on marine organisms and ecosystem function are also possible, but in general less well understood, and have the potential to impact the target species and productivity of both these industries longer into the future.

Market impacts

Pollution incidents of any type in the marine environment have the potential to influence market prices, usually to the detriment of the fishing and aquaculture industries if they result from the perception that the quality of their products has been affected. There are numerous factors potentially influencing market prices at any point in time so definitively attributing changes to a pollution incident is data intensive and challenging. With advance notice, some aquaculture producers may be able to harvest at least part of their stock early, before the oil spreads and conditions prevent them from operating, which may adversely affect prices through flooding the market with smaller than normal sized product. The potential for this, however, is limited.

Most price changes following a pollution event are largely the result of consumer concerns of quality, and in some cases safety of the product (Chang *et al.* 2014). Reductions in demand due to media fuelled concerns over quality were seen after the *Braer* oil spill in the Shetland Islands, even for components of the fisheries that were completely unaffected by the pollution (Goodlad 1996). A fisheries processor was compensated by the IOPC after it was determined that it had lost an order for processing mackerel due to the *Braer* incident (IOPCF 1995). Market prices for Galician mussels are also reported to have fallen after the *Prestige* spill, despite not having been directly affected by the oil themselves (Loureiro *et al.* 2006). Similarly, the demand for oysters in the states contiguous to the Gulf of Mexico decreased substantially immediately following the Deep Horizon oil spill in 2010, and remained below pre-spill levels eight months later (Morgan *et al.* 2016). In contrast, the strong integration of the US shrimp industry into the world market prevented prices from increasing as supply declined, and precipitated an increase in imports to fill the gap (Asche *et al.* 2012). The costs of regaining public confidence can be significant and may require dedicated marketing measures (Goodlad 1996; Loureiro et al. 2006; Cheong 2012), all of which are additional costs of the oil spill. Once market share is lost it can be costly and time consuming to regain. Marvasti and Lamberte (2016) found increased levels of anxiety following the Deepwater Horizon spill caused a persistent increase in price volatility (i.e. increased price risk) for red snapper caught in the Gulf as well as a short term decrease in prices.

Estimates of the market recovery time varies largely by species, with molluscs such as oysters, mussels and clams believed to have a longer recovery time (1-7 years) than finfish (1-2 years) (Sumaila *et al.* 2012). The sessile nature of molluscs and their resultant inability to avoid the oil, as well as their filter feeder nature contribute to consumer uncertainty over their safety (Lin and Milon 1993). Some studies have found fairly rapid responses – both in terms of declines in fish price and recovery – in some cases lasting just a few weeks after the spill (Born *et al.* 2003). Other studies have found that consumers are still reluctant to purchase fish and shellfish for some time after a fishery has been re-opened after a spill even though testing has found the concentrations of hydrocarbons to be within acceptable levels (Moller *et al.* 1999). In contrast, consumers' response to other potential toxic contaminations such as that produced by red tides tends to be much shorter term, e.g. limited to the period for which the fishery is closed (Jin *et al.* 2008). This may reflect the more frequent occurrence of red tides and their more "natural" origin.

Reductions in supply as a result of production impacts can positively influence prices. The reduction in landings of most species in the Gulf of Mexico resulted in short term price increases for these species, despite almost 25% of the consumers saying they reduced consumption due to health concerns (Upton 2011). For example, oyster prices in the Gulf of Mexico were estimated to increase

by 17% post-spill, despite the reduced demand (Morgan et al. 2016). However, once production regained pre-spill levels, prices fell to lower levels than before the spill, largely as a result of the overall reduced demand (Upton 2011). In some cases, higher prices due to reduced supply may attract imports to the region (Jin et al. 2008), reducing the price and the potential offsetting effect on the local fishers.

Production impacts

In some cases, the oil (and dispersants used in its clean up) can affect the survival and productivity of the fish, with subsequent impacts on stock size and catches in the fishery. A study on the potential fisheries impacts of the Montara oil spill identified several species that were highly susceptible to oil pollution, particularly their eggs and juvenile stages, as well as several habitats supporting different fish species (Young et al. 2011).

Irrespective of the impact on fish survival, most fisheries affected by an oil spill are closed to fishing for some time. During the Deepwater Horizon spill, 37% of the Gulf of Mexico's fishing area was closed to production for at least two months, with areas gradually reopened to the fisheries over the next eight months (Upton 2011). This closure was aimed at ensuring contaminated product did not enter the market (Upton 2011).

Production impacts can also affect production costs. If mortalities or tainting subsequently cause aquaculture businesses to buy unusually high levels of juveniles, shortages of supply can increase the costs they face (IOPCF 2008). Conversely, trade data for smolt producers that supplied fish farmers in the Shetland Islands suggests that in some cases prices could have been negatively impacted by falling demand after the *Braer* spill as farms in the affected areas were unable to operate as usual and not in a position to stock fish (IOPCF 1995).

For fishing fleets using mobile gear, the impacts of an oil spill can be reduced through temporarily relocating fishing effort. This may result in an increased fishing cost, as fishers have to travel further to take the catch. Such a response, however, may have unanticipated costs also. Increased fishing pressure in the unaffected areas may have an impact on the level of profitability for the boats previously operating in the area (Collins et al. 2003).

The potential extent of these short and longer term impacts can be seen from the subsequent studies following the Deepwater Horizon oil spill in 2010. A survey of commercial fishers in the Gulf of Mexico in December 2011 found that commercial fishers were shut down for an average of 6 months immediately following the spill (with a standard deviation of 2.5 months) (Posadas 2015), even though much of the area was re-opened to fishing three months after the initial closure. Charter boat hire (for recreational fishing) was shut down for a similar time period (Posadas 2015). As a result, in 2010, commercial and charter sector revenues declined by 60% and 54%, respectively, relative to 2009 (Posadas 2015).

Longer term, however, the closure is believed to have produced some benefits. Catches of shrimp and many fish species in oil affected areas were found to be greater after the spill (Hale *et al.* 2015). In the case of the shrimp, the mechanism underlying the higher abundance in the areas affected by the oil was uncertain: the fishing closures may have enhanced spawning and allowed more young fish to survive, or the exposure to the hydrocarbons may have slowed the growth of the shrimp, delaying their movement out of the estuaries into the deeper water (and hence increasing their abundance in the main fishing areas) (van der Ham and de Mutsert 2014). For the fish species, no significant impact on the juveniles in oil affected seagrass habitats was detected, and reduced fishing pressure during the closures resulted in increased spawning activity and subsequently higher catches (Fodrie and Heck 2011).

In terms of habitat, results were also mixed. Oil affected salt-marsh that was in good condition prior to the spill recovered quickly (within 18 months), whereas salt-marsh already subject to erosion from other pressures eroded at a faster rate and did not recover (Silliman *et al.* 2012; Cornwall 2015).

Recreational fishing impacts

Studies on the impact of oil spills on recreational fisheries are less common. As noted above, Posadas (2015) estimated the impact on charter vessels following the Deepwater Horizon oil spill, but this excludes the impact on non-charter related recreational fishing. Alvarez *et al.* (2014); 2015) estimated the non-market welfare loss to recreational fishers as a result of loss of access to the fishery. Assuming a 25% reduction in the number of trips, Alvarez et al. (2015) estimated that welfare costs may be in the order of US$78m. These estimates have been heavily criticised (Train 2016) and defended (Alvarez *et al.* 2016), highlighting the difficulties in deriving such estimates.

Qualitative assessment of potential commercial fisheries impacts in the GAB

A qualitative assessment of the potential impacts on the fisheries in the GAB was developed based on the review of impacts elsewhere. The assessment involved three components:

1. Identification of the potential impacts arising from onshore related development;
2. Identification of the potential impacts arising from offshore activities; and
3. An assessment of the potential impacts of an oil spill on the fisheries.

The latter assessment is based on a Bayesian Belief Network (BBN), a qualitative modelling framework that provides a probabilistic distribution of outcomes based on a number of assumptions around interactions in the marine environment.

Potential impact related to onshore developments

Onshore impacts will be largely dependent on where the onshore development takes place. Given the spread of the oil exploration leases, it is assumed that onshore activities will take place at both Ceduna and Port Lincoln (or areas near to these) if leases prove productive. Given this, the main sectors that may potentially be affected by these developments are the oyster and SBT ranching industries, and parts of the Marine Scalefish and abalone fisheries. Parts of the rock lobster and prawn fisheries are also present in these areas so may experience some impacts.

From the literature review, onshore development has the potential to create an increased demand for labour in the region. Unemployment in the region is relatively low, around 4.8% in Port Lincoln and 6% in Ceduna, both lower than the 8% unemployment rate in Adelaide (December 2015, Department of Employment small area labour market estimates, https://docs.employment.gov.au/node/34691). The region has had a long history of exposure to the mining industry, as well as heavy industry (e.g. steel works), and fisheries would have already had to compete with these industries for crew members. Much of the labour employed in fisheries is relatively unskilled, whereas the introduction of on-shore related activities is likely to require skilled labour. As a consequence, the impact of these developments on labour demand in most of the fisheries sectors in the region is likely to be small, if not negligible.

Similarly, the pre-existence of a mining industry in the region, including associated activities around the export ports, would mean general inflationary pressures (particularly housing) would not increase substantially with the introduction of on-shore facilities to support the oil industry. Further, improved infrastructure in the region may help to reduce some transport costs.

A study of fisher satisfaction in the region found that around half of the fishers in the Marine Scalefish Fishery were unsatisfied with their income, and around 20 per cent would be prepared to leave the industry if a viable alternative opportunity arose (Triantafillos *et al*. 2014; EconSearch 2015). This fishery is also subject to consistently low levels of profitability, with negative returns earned in several recent years (Pascoe and Innes 2017). The development of an oil industry in the area, if it were to draw labour away from fishing, may result in benefits to this fishery through reducing excess capacity.

The fishing industry is currently well supported in the region in terms of access to port, wharf and associated engineering services. The types of gear and vessels used by these fisheries have little in common with the oil and gas industry so there will not be any significant impact on repair or maintenance costs. Given their specialist nature, oil and gas industry facilities are generally maintained in situ or sent overseas for overhauls. In terms of congestion within ports, the region is currently a hub for agricultural and mineral exports, as well as cruise ship traffic. Several large ports exist in the area (Port Pirie, Wallaroo, Whyalla and Port Lincoln in Spencer Gulf; Thevenard near Ceduna; and Port Adelaide in St Vincent Gulf) with the potential for fisheries conflicts. However, numerous smaller ports also exist in the region that offer alternatives for fishing vessels. These ports would remain accessible to the fishing industry.

Potential impact related to offshore activities

Key offshore activities identified in the review as causing potential conflict with fisheries include loss of access to fishing areas, impacts on the fish stocks due to produced water discharges and potential impacts through seismic surveys.

Most of the proposed offshore activity takes place in the deep waters of the continental slope, some 300 km from shore. In contrast, most fishing activity within the GAB takes place inshore on the shelf itself, hence the two activities will be largely geographically separate. The only fisheries potentially affected by the physical structures are the southern bluefin tuna (SBT) and GAB trawl fisheries. Both fisheries are widespread in their range, and the potential exclusion zones are small in comparison. In the case of SBT, which is a highly mobile and migratory species, the stocks will pass though the exclusion zones (if they go near them at all), and will be available for fishing either before they enter a zone or on their exit.

From the review, produced water and seismic activity during the exploration phase are unlikely to have any major effect on the fisheries. Experiences elsewhere suggest that produced water at worst has a highly localised impact on resident fish species. As the main species caught in the area are relatively (or in the case of SBT highly) mobile, it is unlikely that the development will have any substantial impacts on the fish stocks. Seismic surveys during the activity phase may potentially affect the migration path of SBT (as part of an avoidance strategy), although this is highly uncertain and the extent to which such effects might persist is unknown. However, as these fish do not follow exactly the same trajectory each year, fishers have developed advanced search capability to find and track the SBT.

Where changes in fish catch rates have been observed in other fisheries as a result of seismic surveys, they have been transitory and localised, within 9 km of the blast and lasting only 24 hours (Hirst and Rodhouse 2000). The surveys themselves are also short term in nature.

Potential impacts of an oil spill

From the review, the greatest potential impact in terms of costs to the industry is an oil spill. While the occurrence of these has decreased, if a spill were to happen its consequences may be substantial,

or conversely it may have little impact. The actual effect depends on a wide range of factors, including where the spill occurred in relation to the fisheries, how large the spill was, the biophysical effects of the oil on the species and related habitats, and the duration of the fishery closure. Other factors also include the impact, if any, on prices, the ability of the vessels to relocate fishing effort and the costs associated with this, and also the resilience of the industry to survive a short term impact. These last set of factors vary by fishery and the species which they target.

Relatively few models have attempted to assess both the environmental and economic impact on fisheries of an oil spill (Grimsrud *et al.* 2015). Several models have been developed to estimate costs of oil spills, such as that developed by Kontovas *et al.* (2010), who estimated the average and marginal cost associated with oil spills from data from the International Oil Pollution Compensation Fund (IOPC). The complexity and uncertainty surrounding interactions resulted in the development of several probabilistic models that utilise Bayesian Belief Networks (BBNs). These are largely qualitative models that do not model process, but rather expected probabilities of outcomes given particular combinations of events. These probabilities are based on combinations of expert opinion, data and previous experiences cited in the literature.

Several BBNs have been developed to examine oil spill consequences and largely focus on environmental impacts. For example, a fairly simple BBN was developed to look at the ecological risk of oil spill based on potential impacts on different species groups (Aps et al. 2009a), and from this assess the potential benefits of different at-sea interventions (Aps et al. 2009b). Lecklin et al. (2011) developed a BBN to assess the impacts of an oil spill on a range of marine species. Helle et al. (2011) assessed the effectiveness of different approaches to address an oil spill at sea and the resultant impact on inshore fisheries and aquaculture. A review of the potential usefulness of BBNs as environmental decision support systems for oil spill response strategy selection was undertaken by Davies and Hope (2015), who concluded that BBNs can help ensure that the optimum response strategy is identified, minimising the environmental, social and economic damage.

In most cases, the previous BBNs did not consider economic consequences. The exceptions to this were BBNs developed by Montewka *et al.* (2013), who looked at the clean-up costs following a spill, and Carriger and Barron (2011), who developed a model of the Deepwater Horizon spill that included the costs of loss of ecosystem services.

In our study, we have developed a BBN to provide a qualitative assessment of the economic impacts of a number of scenarios on the key fisheries in the GAB. The BBN captured the key range of factors – biophysical and economic – identified above, and focused on the potential economic consequences for the different fisheries.

The BBN

The structure of the BBN, illustrated in Figure 2, was developed based on the observed impacts elsewhere identified in the review and knowledge of the fisheries developed through several previous fishery-specific studies, including the baseline study by Pascoe and Innes (2017).[3] Unlike most of the previously cited BBNs relating to the impact of oil spills on the marine environment, the model considers economic impacts, such as the effects on markets and costs, as well as the potential impacts of management response such as area closures.

The assumed impact of any oil spill will depend on its size and duration, its proximity to the fishery and also the impact of wind, tides and currents on the delivery of oil into the fishery, in this case defined by the season in which the spill occurs. Two hypothetical oil spill scenarios were modelled by

[3] Further details on the fisheries specific studies are provided in the Appendix.

BP, which estimated the probability of oil reaching particular parts of the GAB at levels of at least 5 microns (equivalent to 5 g/m^2) (BP Developments Australia Pty Ltd 2015a; 2016). While the tolerance of different species to oil varies substantially, 5 microns was assumed to be the minimum level at which detectable impacts are likely. In contrast, French-McCay (2009) found that the impact thresholds are 1 kg/m^2 (1 mm) for vegetation/habitat and 100 g/m^2 (0.1 mm) for invertebrates.

The impact of these scenarios on the species and habitats is dependent on the quantity and also the tolerance of these to oil. The tolerance of species, sensitivity of habitats and impacts on the key stocks were based on findings from the assessment of the Montara oil spill (Young *et al*. 2011). This study did not consider particular tolerance levels for each species or habitat, with the extent of the impact largely assessed through expert opinion developed through workshops. Several of the species affected by the Montara spill are also present in the GAB (e.g. …), so the results were directly transferable. For the other species, experiences elsewhere were used to assess the potential impact on the species. This may result in overestimating the potential impact in some cases where higher levels of oil were responsible for the identified impacts.

The overall probability that a sufficient quantity of oil with the potential to affect fisheries (taken as 5 g/m^2) reaching a particular area was calibrated using the probabilities estimated by BP Developments Australia Pty Ltd (2015a); 2016) and illustrated in Figure 3. The probabilities and their ranges developed by the BP stochastic modelling were used to generate 1,500 potential outcomes for each location and each oil spill duration (500 each for summer, winter and the transitional periods). The learning function within NETICA (Norsys 2014) was used to derive the conditional probability tables (CPTs) for the overall probability of an impacting quantity of oil. The probability of oil reaching levels sufficient to impact species was largely determined by the effects of winds, tides and currents, which varied by season. For example, currents pushing the oils mostly away from a fishery (i.e. a very weak influence on the fishery) would have a higher probability of a low impacting quantity than a fishery that was in the direction of very strong currents. The combination of these factors was captured in the seasonal variable, with the transitional season effectively representing autumn and spring.

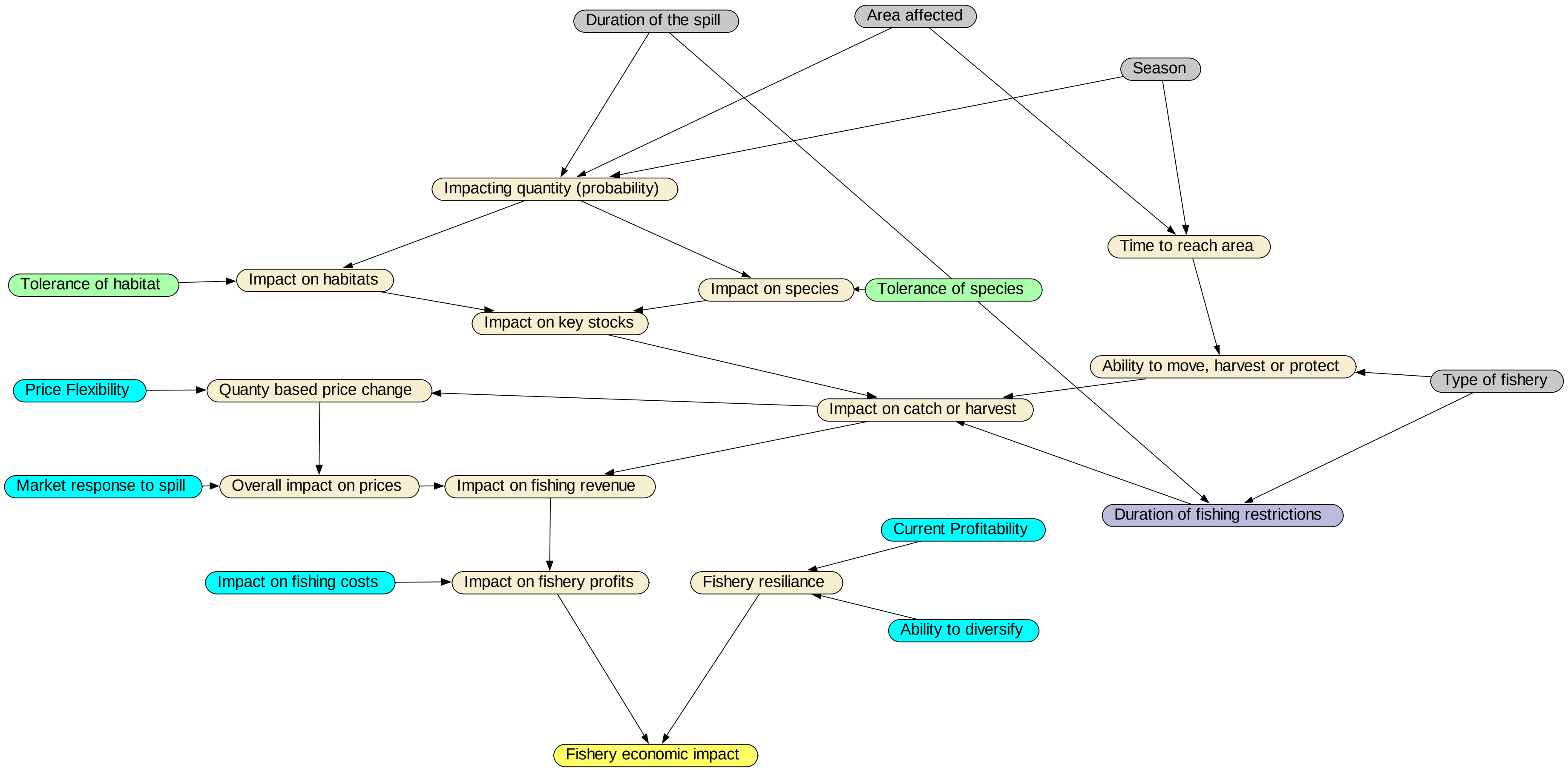


Figure 2. Structure of the BBN

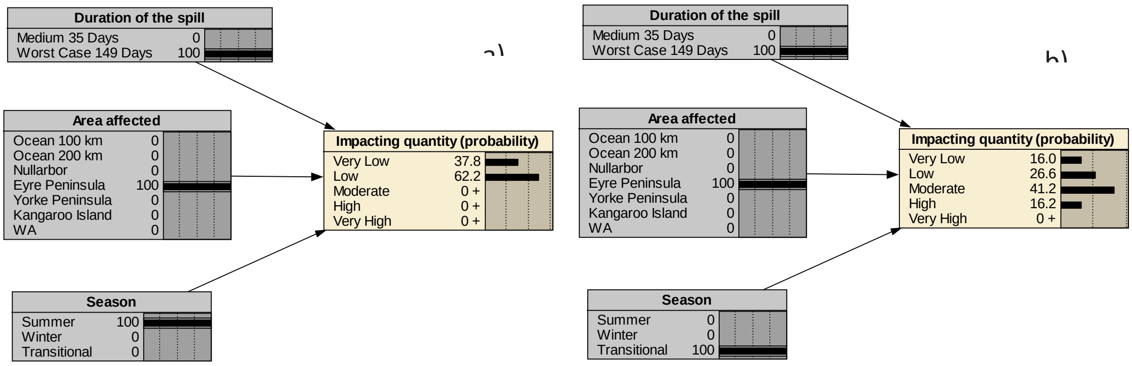


Figure 3. Effects of season a) summer; b) transitional

Individual fishing vessels often operate in the same location from year to year. While this is often considered "habit" (Holland and Sutinen 2000), a range of underlying factors – economic and social in particular – often influence this behaviour that, in the absence of any external change in conditions, result in an apparent inability (e.g. due to licence restrictions) or unwillingness of the vessels to fish in a variety of areas (Salas and Gaertner 2004; van Putten *et al.* 2012). Experiences elsewhere (e.g. Lédée *et al.* 2012) have shown that, unless constrained by management restrictions, fishers are likely to change their behaviour in the face of an externally driven event affecting their main fishing areas, either through (temporarily) ceasing fishing or relocating their fishing effort.

In the model, the ability to move, or in the case of aquaculture harvest what is available and/or attempt to protect the remainder through barriers or other methods, was assumed to be a function of type of fishery and also the amount of warning given (i.e. the time for the oil to reach the area). As with the probability of oil reaching the areas, the minimum expected time for this to occur was estimated by BP Developments Australia Pty Ltd (2015a); 2016). This in turn was a function of the season (which determined the currents, wind, etc.) and the location. As with the probability of an impacting quantity of oil, minimum times estimated by the BP stochastic modelling were used to generate 1,000 potential outcomes for each location and each season (assuming the actual time was between the minimum and 25 per cent higher than the minimum times). The NETICA learning function was again used to estimate the CPT for the node, breaking the times into five discrete time ranges.

Changes in catch will directly impact fishing revenue, but may also affect the price. Price-quantity interactions, in the form of price flexibilities, are derived from other studies (Bose 2004; Pascoe and Innes 2017). Price flexibilities represent the percentage change in price as a result of a one percent change in quantity landed. Prices may also be impacted through consumer concerns about seafood safety. From the review, this is likely to be higher for inshore species such as oysters and abalone than deeper water fish species. The combination of price and quantity landed affects the degree to which revenues are impacted.

Where vessels are able to relocate to reduce the direct impact on catch, this is likely to increase their fishing costs. The change in costs and revenue combine to determine the impact on profits.

The overall impact on the fishery will depend on the impact on profits, and also the ability of the fishery to carry these short term losses. Resilience reflects the ability of the industry to absorb the impacts of an external disturbance, and to recover and rebuild itself to a functional state (National Academies of Science 2012). Measuring resilience is not straightforward. Attempts at developing a fisheries resilience index (Swann 2015) have focused more on planning and preparedness of the

industry for a major impact, while other studies have suggested that resilience is dependent on the level of support available in the broader social and economic system (i.e. financial and social) (Greenhill *et al.* 2009). van Putten *et al.* (2013) suggested that two key elements of a fishery's resilience were its level of profitability and ability to diversify fishing activities (i.e. either spatially or through targeting different species). This latter "measure" of resilience was adopted for the BBN.

The different components of the BBN are linked through a series of CPTs, which describe how the different input combinations result in different probabilities of a particular outcome. As with many other BBN studies (Phan *et al.* 2016), these were developed using a range of approaches including expert knowledge, stakeholder knowledge and empirical data. The CPTs and the assumptions and information sources used to develop the probabilities are given in Appendix A.

Hypothetical oil spill scenarios tested

Two hypothetical oil spill scenarios were examined based around the modelling work undertaken by BP (BP Developments Australia Pty Ltd 2016):

- A deep water oil spill of 35 days duration (the expected maximum length of an oil spill) at the drill site (a "medium" spill)
- A deep water oil spill of 149 days duration (the worst case scenario based on failure to stop the spill at 35 days as expected) at the drill site (a "large" spill)

These scenarios assumed failure of a capping stack in permit area EPP39 located approximately 180km offshore in the central Great Australian Bight off southern Australia at a depth of 2,248m. The area is approximately 415 to 655 km west of Port Lincoln, and 250 to 530 km southwest of Ceduna. The impacts of each hypothetical scenario were examined for a range of fisheries, and for each season.

A worked example: Southern Bluefin Tuna given a large summer spill

The BBN of the scenario for the wild-caught Southern Bluefin Tuna fishery (i.e. excluding the ranching activities) is given in Figure 4. Most of the fishing activity in the SBT fishery takes place to the north east of the centre of the spill. The direction of the currents during the summer is largely away from the main fishing grounds (so a very weak effect), but some oil will still move to the area given its close proximity to the spill.

The tolerance of the species during the summer is assumed to be high. Abundances of larvae of Atlantic Bluefin Tuna in oil affected areas within the Gulf of Mexico reduced roughly in proportion to the spawning area affected (Muhling *et al.* 2012). However, these changes were within normal bounds given inter-annual variability (Rooker *et al.* 2013). Subsequent declines in abundance of several large pelagic species in the Gulf may suggest that adults avoid returning to the affected area, either as a direct result of the earlier oil spill or in response to reduced quantities of prey species (Rooker *et al*. 2013). Spawning of SBT does not take place in the GAB, so impacts on eggs and larvae are not a consideration. The current fishery targets juvenile fish (2-5 years old) for grow out in the associated SBT ranching industry. Sensitivity of juvenile SBT was considered moderate by Young *et al*. (2011). The supporting function of habitat is unlikely to be affected by the spill (Young *et al*. 2011).

The fishery in the GAB generally operates over a short duration (around 10 weeks) between December and February (i.e. the summer months). The main fishing grounds correspond to areas likely to be affected by the summer oil spill, although the potential to take the catch slightly further to the east may exist and the vessels are easily moved. Given the direction of the currents in summer, any closure

of the grounds for SBT will be relatively short. A slight cost increase is therefore possible (assumed half way between none and medium). The catch from the GAB is transferred to the SBT ranching sector inshore through towing cages, and it is assumed in the scenarios that this process is not affected by the oil spill.[4] No market price response is expected.

While no recent economic assessment has been undertaken of the fishery, it is believed to be highly profitable. Fishers in the SBT are also able to readily move their activity, so resilience is likely to be high.

The BBN also produces two scores: one representing the impact on fishery profits, and the other an overall fishery impact score taking into account the resilience of the fishery. These are relative measures with a potential range of 0 (no impact) to 3 (high impact). The former represents the magnitude of the impact, the second represents the ability of the fishery to cope with the impact in the short-medium term. The SBT scores (1.68 and 1.07) suggest a moderate potential impact, as indicted by the probability distribution in the last box within Figure 4.

Reducing the spill duration from 145 days (worst case) to 35 days results in a score reduction to 1.51 and 0.94, respectively. In both cases, the magnitude of the scores is largely driven by uncertainty around the impact on the stock. While tolerance of the species is high, the relatively closeness of the fishery to the oil producing areas is the main driver of this uncertainty.

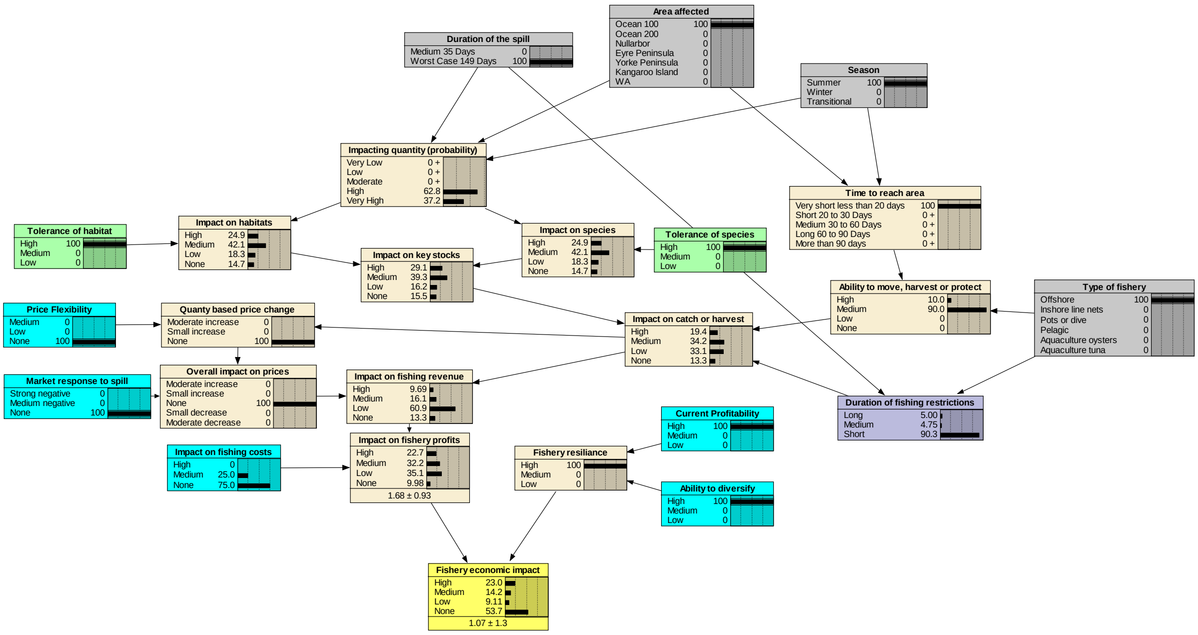


Figure 4. Example BBN scenario: SBT with a large summer spill

Results for other fisheries

The full results for a range of other key fisheries in the GAB are given in Appendix B, and the main results summarised in Figure 5. The key outputs of the model are presented for the two key

[4] The impact on the grow-out stage is assessed separately. While linking the fishery component to the aquaculture component would be preferable, this would require a more complex model, and may be an area for further consideration. The initial analysis assumes that the catching and grow-out sectors involve discrete activities.

hypothetical oil spill scenarios (145 days and 35 days duration), with the impact estimated for different seasons in which the spill may occur (which influences the current strength and direction and hence the oil distribution). The impact is expressed as a relative scale, with 0 being no impact and 3 being a substantial impact. Two measures are presented in Figure 5. First, the relative impact on fishery profits is estimated (Figure 5 (a) and (b)), and then the broader impact of this on the fishery taking into account the fishery resilience (Figure 5 (c) and (d)). Fisheries that are highly resilient (as determined by current profitability and their ability to diversify), such as the SBT and Abalone fisheries, experience reduced economic impact scores. In fisheries with lower resilience (e.g. Marine Scalefish Fishery), the overall economic impact score is increased.

These results provide a relative measure of adverse fishery impact in the event of oil spills that resemble the scenarios examined. The results are presented as an overall impact score, with zero indicating no impact and three indicating a (relatively) severe impact. It represents a relatively short term impact only, based on observations from previous oil spills elsewhere. Hence, longer term population size consequences (if any) are not examined. However, comments about the longer term impact of an oil spill on recruitment are included in the description of each scenario, and in most cases these are not considered to be substantial.

The oyster industry is predicted to experience the greatest potential impact, but this is more a result of market driven forces than biophysical. Bans on oyster sales from affected areas are likely to occur due to their perceived contamination and potential health effects. This may make the crop effectively unmarketable even though actual mortality may be low. For this reason, the scores between the different seasons were similar, even though the quantity of oil potentially affecting the oyster beds varied substantially. Allowances were made for the potential for growers to harvest some or most of their crops early if time permitted, but this was assumed to be at a lower price (due to the smaller size of the oysters).

For most other fisheries, the short term impact is likely to be less, with most of the impact on the fishery a consequence of the assumed closure. This can be mitigated to some extent by the ability of the fishers to relocate effort elsewhere (where licences permit) or diversify into less affected fisheries, and for some species the reduced quantity landed may result in a slight price increase. In the case of the gillnet, hook and trap fishery (GHT), much of the economic cost was associated with potentially relocating fishing activities (increasing fishing costs) as well as negative consumer responses to their product.

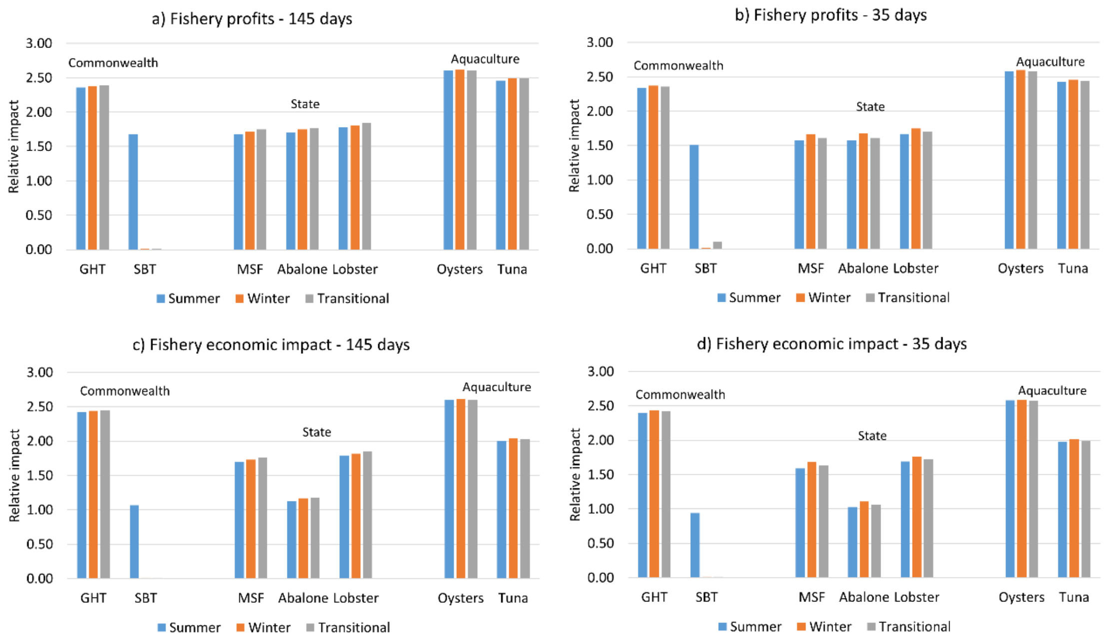


Figure 5. Outcomes from BBN models – overall relative impacts scores

The longer term consequences for some industries will vary substantially and for different reasons. For example, the oyster industry, which relies on hatchery reared spat, may recover production levels within one or two years (assuming an 18 month grow out), but may have an adverse ongoing market response for several years. Sumaila *et al.* (2012) suggested that the market recovery time may be as high as seven years for shellfish. For most fish species, the main impact will be shorter term unless there has been some impact on eggs or larvae. Many adult fish were found to be fairly insensitive to oil (in a mortality sense), although eggs and juveniles were often highly sensitive as determined from the analysis of impacts of the Montara oil spill (Young *et al*. 2011).

A comparison of the potential relative impact on profits (based on a large summer spill) and the value of the fishery is given in Figure 6. While oyster farming had the highest absolute impact, SBT ranching may be at greater overall risk given its substantial value of production. In contrast, the GHT fishery, which experienced the greatest potential impact of the wild caught fisheries examined, has a low value of production compared to other fisheries. When the resilience of the fisheries is considered (Figure 7), the relative position of several fisheries improves, including SBT ranching.

Much of the impact on the fisheries was less related to the biophysical impact on the stocks, and more due to the impact on prices, length of any fishery closure, and additional costs due to relocation or avoidance activities (if possible). As a result, there is relatively little difference between outcomes under the large (149 day spill) and the medium (35 day spill) scenarios. Studies elsewhere have focused more on the biophysical impacts of oil spills on fish stocks (Aps et al. 2009a; Aps et al. 2009b; Carriger and Barron 2011; Lecklin et al. 2011), ignoring the market and behavioural responses of fishers. The results of this model suggest that greater focus on these latter effects is needed, and strategies to deal with these impacts need to be factored into any oil spill response.

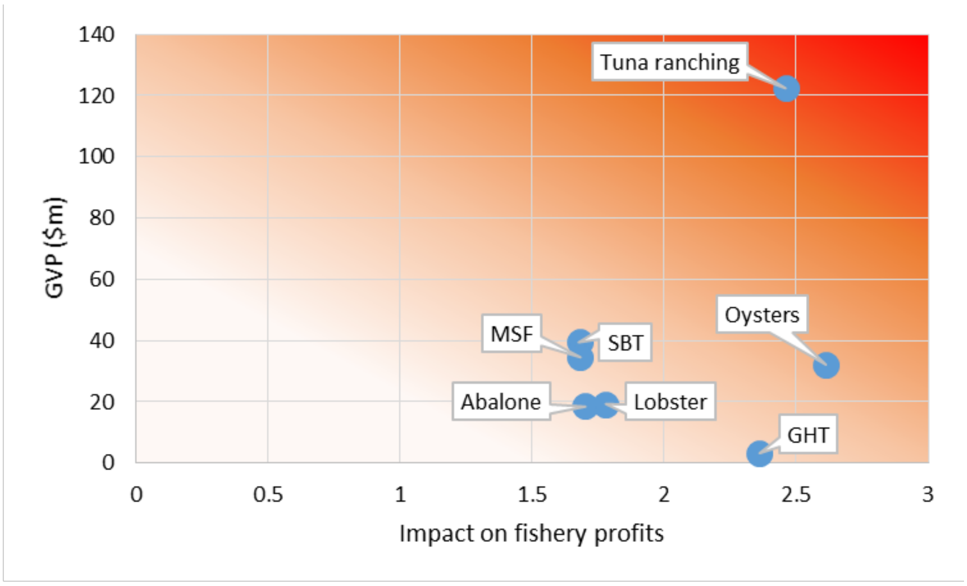


Figure 6. Impact on fishery profit scores versus gross value of the fisheries

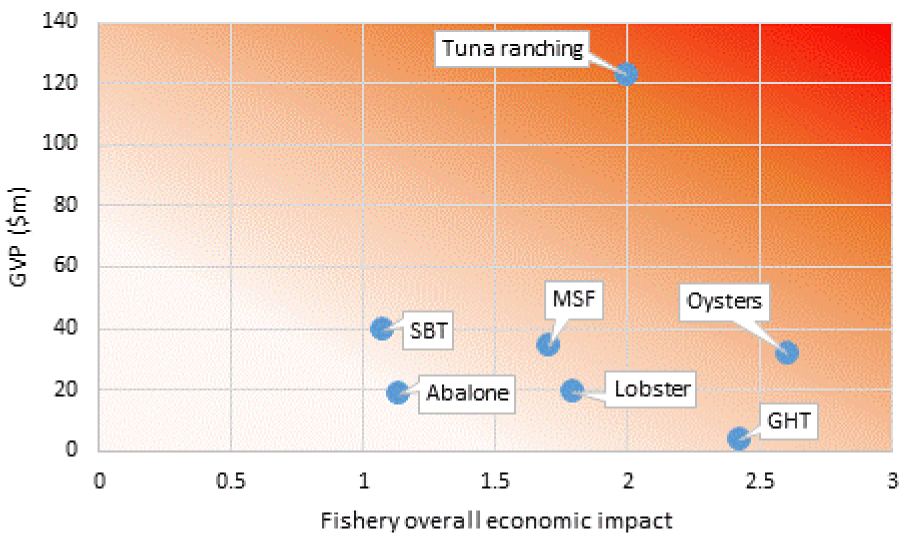


Figure 7. Overall economic impact scores versus gross value of the fisheries

Limitations of the BBN models and potential for future development

The model captures the key relationships that are likely to determine the potential impact of an oil spill on the fisheries examined, but as with any model, it is a simplification of the system, and as such should be viewed as illustrative of the potential outcomes rather than predictive. As there has not been an oil spill in the region from which to observe impacts, the model is predicated on a large number of assumptions. These assumptions are largely drawn from observed impacts on similar species elsewhere, so are realistic to a large extent, although the different environment (natural, social and economic) in the GAB may result in different degrees of adaptation and impact than those captured in the BBN.

A common BBN framework was also applied to all fisheries (and aquaculture) examined. A fishery specific BBN may look different to the generic model developed and applied in this study, as it may

capture features specific to the fishery that influence outcomes. Similarly, the CPTs linking the components are mostly based on a relatively simple algorithm derived from the subjective assessment of the importance of different parent nodes on a child node outcome.[5] These subjective probabilities are based on observations elsewhere as well as theoretical relationships (i.e. revenue is equally affected by a given percentage change in price or catch). While expert opinion was used to develop some relationships, greater expert involvement would be useful covering a wider range of fisheries. The relationships are also assumed to be the same for all fisheries, when in fact they may vary between fisheries. Developing fishery specific BBNs was beyond the scope of this study, but the models presented should prove useful as the basis of more fishery-specific analyses in the future.

Finally, the BBNs assessed each fishery in isolation, whereas cumulative impacts and/or interactions between fisheries may result in different or greater impacts. For example, the SBT fishery and the SBT ranching sectors are inextricably linked; the latter cannot exist without the former. Again, fishery specific BBNs may be developed including these links which may improve the reliability of the model outcomes. Also, as many fisheries overlap geographically, the cumulative economic impact on an area/region may be greater than the sum of the individual impacts on the adjacent fisheries. Cumulative impacts from multiple threats (oil based and non-oil based) may also be significant in the region. Further model development may address these issues.

Review of methods for assessing fisheries and aquaculture impacts of oil spills *ex post*

The focus of this section is on identifying methods for the ex post evaluation of the impacts of an oil spill on a fishery, based on a review of international experiences. Studies that have examined the cost of an oil spill on fisheries generally fall into two general groups: 1) studies that have reported compensation claim methods and/or payments made following an oil spill; and 2) studies that have attempted to estimate the overall impact on fisheries of an oil spill retrospectively using either historical data or modelling. The magnitude of impact generally differed between the study types, with the largest costs generally coming from retrospective economic estimates followed by compensation claims and then compensation paid (Thébaud *et al.* 2005).

Previous studies have found that the economic impact of an oil spill is difficult to evaluate with precision, given the limitations in available baseline data and understanding of longer term impacts in a dynamic industry. While direct property damage is fairly easy to determine, establishing causality between oil spills and broader losses in income and market share is more difficult to establish (Chang *et al.* 2014). The divergence in cost estimates between the different studies was primarily attributed to the difficulty of quantifying monetary values for compensation (i.e. data deficiencies, methodological limitations), and strategic behaviour by claimants (Thébaud *et al.* 2005).

The methodology underlying the estimation of compensation claims is often less transparent, but in some cases methods have been prescribed as to how and what to measure. Retrospective analyses – model or data based – have also used a range of methods. These have been largely “academic” in that they were not aimed at supporting a compensation claim, but rather to inform the general scientific communities, management agencies and general public about the magnitude of costs.

The scope of the costs considered also varies substantially between studies. From the literature, the greatest costs associated with an oil spill are generally not fisheries related. Clean-up costs associated

[5] The key exception here is the time taken for the oil to reach an area and the likelihood that a critical volume of oil will reach an area, both of which are derived from BP modelling (BP Developments Australia Pty Ltd 2016).

with an oil spill are generally substantial, as are costs associated with flow on impacts to the regional economy, tourism related impacts and also non-market costs associated with environmental impacts. These costs are not considered in this review, as the focus is on direct fisheries impacts. Costs to recreational fisheries are not considered in the review as they are particularly difficult to assess, and because recreational fishers may substitute other recreational activities for fishing (Ditton and Sutton 2004), or a different type of fishing activity (Sutton and Ditton 2005), and hence the net loss in benefits may be substantially less than simple fishing activity based measures suggest.

Compensation claims focused assessments

Most published compensation based assessments have involved European oil spills, which have been covered by the International Oil Pollution Compensation Funds (IOPCF).[6] The IOPCF has a standardised claims process for considering both fisheries and aquaculture losses (IOPCF 2008; 2014) and the extent of any compensatory payments made under the 1992 Fund are also conditional upon the expectation that business will do whatever is within their power to mitigate their losses when a spill occurs, e.g. fish elsewhere[7] or harvest stocks earlier/later if these are practical options.

Quantifying any direct impacts at the individual level for resource users such as commercial fishers and aquaculture businesses can be relatively straightforward and is arguably the most commonly applied approach for the purpose of assessing compensation payments. The assessment of impacts on fishers, aquaculture businesses, or dependent industries under the 1992 Fund tends to focus mainly upon property damage and pure economic losses, such as:

- Property damage at its residual value (i.e. once depreciation is accounted for)
    - e.g. gear or infrastructure such as nets, traps, buoys, fish pens
- Lost revenue if there are closures and no alternative areas to fish, or if the alternative has higher costs
- Higher levels of mortality in aquaculture facilities which reduce revenue
- Loss of revenue due to the inability to sell product due to market concerns over quality

Under the IOPCF rules, claims are made by individuals, each having to provide evidence to support their claim. In the case of fishing and aquaculture, this involved providing (amongst other things) a detailed breakdown of catch (by species), days fished and income by month over the preceding three years as well as the year affected.

Compensation under the IOPC is related to loss of business profits, not just loss of revenue. Fishers are therefore also required to provide evidence of costs saved (e.g. fuel, repairs, labour costs) as a result of the reduced fishing activity, and evidence that they took action to mitigate the impacts of the oil spill on their income. Applicants that fail to take adequate action in this respect are subject to claims being considered inadmissible or adjusted to reflect this. An example of one such instance is the IOPC's determination that, despite having demonstrable losses, three relatively large seiner/trawlers intending to claim for losses associated with the *Braer* spill were capable of doing more to mitigate the financial impacts and any submission on their behalf would therefore not be accepted (IOPCF 1995).

Claims can also be made for losses due to the market response to an oil spill even if no physical damage to the vessel or gear or catch reductions occur. Where prices have fallen and a link to the oil spill can

[6] The IOPC Funds provide financial compensation for oil pollution damage that occurs in Member States, resulting from spills of persistent oil from tankers. There are currently 114 States Parties to the 1992 Fund Convention – including Australia – and 31 States Parties to the Supplementary Fund Protocol.
[7] As will be discussed later, this may result in other problems, namely loss of revenue to fishers in "unaffected" areas not eligible for compensation.

be established then business in areas unaffected directly by the oil spill may also seek compensation (IOPCF 2008). As claims are made individually, and may be delayed for several years through court challenges, the final compensation payment is often not known for some time. For example, compensation was still pending for the 2002 *Prestige* spill in 2015 (IOPCF 2015).

IOPCF relates to compensation for oil spills from tankers only. Spills from oil production platforms are subject to different compensation systems, which vary from country to country. In the US Deepwater Horizon spill, claims for economic damage were defined as loss of profits, income, or earnings as a result of the Deepwater Horizon incident. Physical damage to vessels as a result of the spill could also be claimed. The process to make the claims, and the evidence required were pre-defined by the Oil Pollution Act 1990 (National Pollution Funds Centre 2009). To claim loss of profits, fishers were required to substantiate their loss with three years of accounts prior to the spill, as well as copies of vessel logs over this same period. As with the IOPCF requirements, the Oil Pollution Act 1990 required fishers to provide evidence of both loss of revenue and cost savings as a result of the reduced activity (e.g. fuel, labour) (National Pollution Funds Centre 2009)

In Australia, offshore oil and gas producers are required to maintain financial assurance sufficient to demonstrate that they can meet the costs, expenses and liabilities associated with undertaking a petroleum activity (NOPSEMA 2013). As a result, any compensation is negotiated directly with the company responsible. No predefined method is given for how such claims may be assessed, nor the time frame over which claims need to be finalised. In the case of the Montara oil spill, compensation for Indonesian fishers was still under negotiation six years after the event (Mitchell 2015).

A key advantage of estimates of oil spill damage through the compensation process is that they are validated at all levels. However, full details of the combined cost to fisheries is rarely reported on its own, and is usually reported as part of the overall cost of the spill, which often includes (and is dominated by) clean-up and other costs noted above. For this reason, a number of fisheries specific studies have been undertaken to estimate the impacts on the fishing industry directly. These have not been used as a basis for compensation.

Assessments based on historical quantities and values of production

Most previous studies aimed at assessing the economic impact of an oil spill have primarily relied on comparison of fishing activity during (or immediately after) a spill with historical quantities and values of production. The most simplistic, but least informative, of these is where trends in catch weights are used to infer that overall economic losses have occurred (e.g. Cheong 2012). More preferable is to compare the monetary value of landings, used in combination with data relating to catching costs, so that an estimate of change in profit (i.e. economic impact) can be made.

Several studies have attempted to estimate the impact on fisheries associated with the *Sea Empress* tanker spill, which took place off the coast of Wales in February 1996, spilling an estimated 72,000 tonnes of crude oil into the marine environment resulting in the imposition of a three month ban on commercial fishery activity. The amounts agreed for compensation at that point by the IOPC fund for commercial fishing losses was £6.8 million, based on claims of direct losses, and were taken to represent financial losses for these groups (Moore *et al.* 1998). Moore *et al.* (1998) estimated economic losses to the fisheries sector, based on estimated changes in profits, to be substantially lower at between £0.67 and £1 million (although details as to how this figure was estimated are not available). In contrast, Hill and Bryan (1997) estimated the loss in the value of landings to be in the order of £4.7 million over all the fleets affected based on a comparison with the previous year’s fishing activity over the same period. This latter estimated was of revenue only, and did not consider changes in costs.

Short-term impacts on revenues after the *Prestige* spill, which released an estimated 63,000 tonnes of heavy fuel oil off the coast of Galicia in 2002, were assessed for commercial fishing vessels by comparing the quantities and values of their catches after the spill with those for the same periods in the preceding five years. Losses for 2003, the year following the spill, were estimated at €56 million (Garza-Gil et al. 2006a; Garza-Gil *et al.* 2006b). A separate assessment of the same incident similarly utilised recorded reductions in the values of landings for capture fisheries to estimate the overall 2002-2003 revenue losses for vessels in Galicia (€79.4 million), the Basque Country (€39.10 million) and Cantabria (€25.78 million) (Loureiro et al. 2006). Net losses (economic costs) were estimated for Galicia (€63.08 million) and the whole Spanish capture sector (€112.66 million) by accounting also for the cost savings (variable costs, labour) associated with reductions in effort (Loureiro *et al*. 2006). These differences in the cost estimates for the same oil spill demonstrate the difficulty in deriving robust estimates, as they are heavily dependent on the assumptions used even if based on the same or similar data.

Surís-Regueiro *et al.* (2007) also estimated the economic impacts of the *Prestige* oil spill on the Galician fishing sector by both a comparison with previous years' data as well as through a survey of a representative sample of fishers, directly asking how the event affected their income. The cost estimates were comparable using both methods, although the use of the survey introduced a measure of uncertainty into the estimates (based on the variation around the responses of the individual fishers surveyed). This provided an estimated loss of between €76 and €115.5 million in revenues in the two years following the event (Surís-Regueiro *et al.* 2007).

The financial impact of the *Prestige* on Galicia's aquaculture industry (for both mussels and turbot) was also assessed by comparing the quantities and values of production in the year of the spill with averages from the preceding five years, and estimated total losses at €9 million (Garza-Gil et al. 2006a; Garza-Gil et al. 2006b). When factors such as loss of reputation and future income were also accounted for, the financial impact was greater, and estimated to total €12.83 million for Galician mussel producers alone (Loureiro et al. 2006). Only data relating to the main producer group for the region were available for mussel producers so the findings for this group had to be extrapolated up to estimate impacts at the sector level, as the economic cost was not determined in any of the assessments.

The Deepwater Horizon well blowout released an estimated 3.19 million barrels (approximately 447,000 tonnes) of crude oil into the Gulf of Mexico (GoM) over an 87 day period beginning in April 2010 (Deepwater Horizon Natural Resource Damage Assessment Trustees 2016). As noted previously, this resulted in area closures for both commercial and recreational fisheries and reductions in consumer demand for seafood as a consequence of the negative publicity associated with the event.

Several different estimates of the economic impact of the spill on fisheries have been undertaken. Early assessments were limited to considering differences between landings for shrimp fisheries and the oyster industry in the year of the event (2010) with those of the previous year (Upton 2011). The value of these changes, however, were not estimated, and no consideration was given to potential changes in fishing costs. Smith *et al.* (2011) assumed a 40% reduction in catch in the Gulf, from which the loss to the fishing industry was estimated to be $4.36 billion. There was no supporting information for the assumed 40% reduction in catch provided, and the cost savings were also not considered. In contrast, McCrea-Strub *et al.* (2011) estimated the average value of catch taken in the closed areas over the period 2000 to 2005 and from this estimated the impact of the closures on fishery revenues to be less than $250 million. Posadas (2015) surveyed a sample of representative fishers to estimate changes in revenue as a result of the oil spill. The questionnaire asked for estimates of the reduction

in annual sales during 2010 (to the nearest 10%) rather than request information on pre and post revenue levels.

Model based estimates of oil spill impacts

Estimating the longer term impacts of an oil spill is complicated by a range of obfuscating factors. For example, changes in catch may be due to changes in fish stocks, but these are also influenced by other environmental factors. Separating out the effects of the oil spill from other pressures or trends in the fishery may provide better estimates of the impact than a simple comparison of before and after. Several studies have aimed at addressing this through the development of bioeconomic and other statistical modelling approaches.

Bioeconomic models

Bioeconomic models, which have the capacity to explicitly account for and provide information on the dynamic nature of both the commercial fishery and the underlying resource, have been developed to assess the implications of oil spills. One such model, developed to estimate the impacts of hypothetical pollution events, illustrated that the level of impact on commercial fishers, and how this might be distributed within the fleet, had the potential to vary with factors such as the rate of fisher response to an incident and whether the impact was chronic or acute in nature (Collins *et al.* 1998).

The potential distributional effects of area closures are one such potential effect if a spill results in some areas being closed to fishing, and vessels are free to relocate their effort to unaffected areas. In such cases, this can impose costs on fishers already operating in these areas. A spatial bioeconomic model with an endogenous fisher response was developed to assess the impacts of this on fishery costs (Collins *et al.* 2003). The model found that the impacts on directly affected fishers may be reduced through their relocation to other areas, but that this imposed costs on those already fishing in these areas (Collins *et al.* 2003). Area closures imposed as a consequence of the *Sea Empress* tanker spill that occurred off the coast of South Wales in 1996 ultimately resulted in fishers in bordering regions submitting claims for lost income because displaced fishing effort reduced their catch rates (Moore *et al.* 1998). Developing appropriate bioeconomic models for specific fisheries applications requires a good understanding of the characteristics and conditions in both the target stocks and the fleets being assessed.

More recently, Sumaila *et al.* (2012) used a simple bioeconomic modelling approach to forward predict the impact of the Deepwater Horizon spill over a seven year period. Using a number of assumptions with respect to the impact of the spill on resource accessibility and markets over time, the direct effects on revenues, profitability and rents were modelled, as well as the indirect impacts on wages and added value (Sumaila et al. 2012). These impacts were assessed and aggregated over the period of time it was anticipated markets would require to recover (up to 7 years for some species) to provide an indication of the potential overall impact on these sectors. Losses were discounted over time to derive a net present value. The study concluded that commercial fisheries may face total revenue losses of US$1.6 billion and total profit losses of US$0.8 billion over the period of the impact (Sumaila *et al.* 2012).

Statistical models

A statistical (regression) modelling approach was used to assess the impacts of the *Amoco Cadiz,* which spilt 230,000 tonnes of oil off the coast of France in 1978 and resulted in fisheries closures and damages to both local shellfish and finfish fisheries. Monthly value and catch data from commercial finfish fisheries in the affected region were used to estimate a trend-extrapolation model and provide a baseline of expected levels of catch each month in the absence of the oil spill (Grigalunas *et al.* 1986).

This allowed the observed levels of catch to be compared with the modelled baseline and an estimate of impact on the fisheries profitability to be derived.

Statistical models have also been used at a broader scale to consider the net economic impacts of a spill to the region or community in which it occurs. The fisheries in the region affected were concurrently subject to unrelated but deteriorating economic conditions as a consequence of falling demand, particularly for Pacific salmon, which further complicated the task of determining to what extent the spill impacted the fishery. The impacts associated with the *Exxon Valdez* spill that occurred in Alaska in March 1989 were quantified using a single statistical ARIIMA modelling approach, a stochastic time series modelling approach that is used to estimate trends over time independent of external impacts (Cohen 1993). This approach allowed the baseline scenario, i.e. what incomes would have been in the absence of the spill, to be explicitly modelled and directly compared to incomes after the spill. A subsequent statistical modelling analysis of the *Exxon Valdez* spill developed a general market model to focus on the impacts the spill had on prices in the fishery and estimated the impact of these changes on the revenue losses (Cohen 1995).

Other models

In the United States regulations require that a Natural Resource Damage Assessment (NRDA) is undertaken after incidents such as oil spills. As financial constraints and time pressures often make it impractical to construct case specific models for assessing impacts in every instance, generalised models relying on combinations of large datasets and benefits transfer have been developed with the specific purpose of allowing comprehensive NRDAs to be undertaken (e.g. Grigalunas *et al.* 1988; Jones 1992; French *et al.* 1996; McCay 2003; Industrial Economics Incorporated *et al.* 2012).

The Natural Resource Damage Assessment Model for Coastal and Marine Environments (NRDAM/CME) is an integrated ocean systems/economic model that was developed to assess the potential size of compensation related damage claims under the Comprehensive Environmental Response, Compensation and Liability Act of 1980 (CERCLA) and the Clean Water Act (CWA) (Grigalunas *et al.* 1988). This approach uses information relating to the biological, economic, and physical/chemical/toxicological characteristics of the locations and fisheries considered to quantify likely impacts under a range of hypothetical oil spill scenarios, and their sensitivity to variations in the underlying conditions. The modelling of damages using this approach was observed to vary considerably with factors such as the environment, location, and season and demonstrated that these variables should not be overlooked in preference of approaches that focused more on the volume of oil spilt (Grigalunas *et al.* 1988).

The Spill Impact Model Application Package (SIMAP) is another approach that can be used to assist in NRDAs. This modelling approach contains oil fates and effects models that can be applied to different spill events and locations in both marine and freshwater environments (McCay 2003). The SIMAP model was used to undertake a NRDA of the *North Cape* oil spill, a relatively small spill that occurred in January 1996 off Rhode Island. This spill released 2,682 tonnes of heating oil and impacted fisheries through a combination of target species mortalities and area closures. The SIMAP platform allows the physical and biological effects of a spill, and subsequent management efforts, to be spatially modelled (GIS) and quantified in terms of their eventual impact on the biomass and foregone (biological) production.

There is no explicit economic component to the SIMAP, but this has been incorporated into the Offshore Environmental Costs Model (OECM), used by the US Bureau of Ocean Energy Management (BOEM) to assess the net benefits (or costs) of proposed outer continental shelf (OCS) oil and gas projects when compared to alternative sources of energy (Industrial Economics Incorporated et al.

2012). Although the current version of the OECM does not allow for the assessment of oil spill related impacts on commercial fisheries, the model's authors have set out a number of the assumptions that would be required for this to be possible: the spill's biological impact, if any, on future stocks; the relative impact of a spill on different commercial species; the timing of a spill and whether it would occur during a period when commercial activity is occurring at a particular location; and a spill's influence on consumer behaviour (whether demand would change due to real or perceived risks), and the construction of a credible model of spill-related costs (Industrial Economics Incorporated *et al.* 2012).

DISCUSSION AND CONCLUSION

Whilst the development of offshore oil and gas resources certainly has the potential to generate economic benefits for associated communities onshore, careful planning and management is necessary if potential adverse interactions with the fishing and aquaculture sectors are to be avoided or mitigated. At a community level, the impacts of offshore oil and gas field development have been observed to be highly diverse, typically varying on a case by case basis (Baldwin and Baldwin 1975; Austin *et al.* 2002). From the perspective of fishers, the difficulty of accurately foreseeing the impacts of offshore development projects, or necessary mitigation actions, led to the recognition that early and ongoing communication between both industries is essential, and any mitigation packages must be sufficiently flexible to allow unforeseen impacts to be accommodated (Perry *et al.* 2012). To this end, maintaining a close dialogue with fishers during the development stage is essential to reassure them that efforts are underway to minimise any potential risk to their businesses (Chang *et al*. 2014).

Potential fishery related impacts of the development

From the review, the potential consequences and also likelihood of any onshore related impact on the GAB fisheries and aquaculture industries fishery will most likely be negligible in most cases. The fisheries have been exposed to similar onshore pressures as a result of the recent mining boom and extensive port developments along the coast aimed at exporting mineral and agricultural products. Any increase in labour demand affecting the fishery from the development of an oil and gas industry in the GAB may provide an alternative opportunity for those seeking to exit the fishery but without a current alternative.

With the exception of an oil spill, any impacts from offshore activities will also be negligible – both in terms of consequences and likelihood of occurrence. While this was the conclusion of the qualitative analysis, it is also the experience from the development of the Bass Strait oil industry, which has been in operation since 1965. Currently, there are 23 offshore platforms and installations in Bass Strait which feed a network of 600 km of underwater pipelines. More than four billion barrels of crude oil and around eight trillion cubic feet of gas have been produced (Australian Trade Commission 2016). In the 40 years of their operation, no significant fishery impact has been reported in the literature related to the oil industry.

The potential impact of an oil spill varies depending not only on when it occurs, how close the fishery is to the spill and how big the spill is, but also the tolerance of the species and habitats to the oil, the ability of the fishers to relocate their activity, the management response, the market response and also the general resilience of the fishery. These factors were captured in a qualitative BBN analysis. The results of this hypothetical analysis, while illustrative rather than predictive,[8] suggest that most fisheries will experience only a modest to medium impact in the short term even in the event of a large spill due to the remoteness of the oil spill site and the ability of fishers to adjust their activities. Aquaculture activities, particularly oysters, may incur a more substantial short term impact due to their inability to move out of the way of the oil, although there is potential to mitigate this through targeted at-sea response. Mechanical recovery of oil at sea and the use of near-shore barriers was found to substantially reduce the potential impact on inshore fisheries and aquaculture, including molluscs such as mussels (Helle *et al*. 2011). The potential for at-sea mitigation action was not considered in the analysis, so the results provide a worst-case scenario. However, the BBN can help inform where these mitigation efforts might be best directed.

[8] As noted earlier, the generic models may not capture all important interactions in the fisheries. Ideally, fishery-specific models would be developed, although this was beyond the scope of this study.

While potentially having an impact on some fisheries and aquaculture sectors, the likelihood of a spill remains small, and there are strong incentives for industry to minimise the occurrence and impact of spills. Under most countries' legislation, as is the case in Australia, the company responsible for any oil spill is also liable for the costs associated with the spill. As a result, oil spills are costly to the oil companies responsible. The 2010 Deepwater Horizon spill resulted in total payouts of US$20.8 billion (McGill 2016), while the total cost including initial clean-up costs, criminal and civil penalties is estimated to exceed US$53 billion (BP Global 2015). A major cost component of an oil spill is the clean-up and restoration of damaged habitats, which often comprises around two thirds of the total cost of an oil spill, with fisheries costs making up only part of the remaining third (Kontovas *et al*. 2010).

Since the Montara spill in 2009, Australian legislation (the Offshore Petroleum and Greenhouse Gas Storage Act 2006) has required oil companies to provide an assurance that they have adequate funds to meet the costs, expenses and liabilities associated with offshore oil production (NOPSEMA 2013), which includes the cost of an oil spill. The Australian Petroleum Production & Exploration Association (APPEA) provides a guide as to the level of assurance required to meet the requirements of an operational response to an oil spill and well control (APPEA 2014b). The former is estimated to range from $10 million to $500 million depending on the type of hydrocarbon, the potential spill volume and the potential shoreline impact (based on worst case scenario modelling), while the cost of well control is estimated to be twice the cost of the initial well drilling plus $50 million, or $1 million a day with a default assumption of 80 days to cap the well (plus $50 million to cover associated capping costs) (APPEA 2014b). This assurance may take the form of an insurance policy, a deposit or a bond (or a combination of these) (APPEA 2014b), all of which are costs to the industry. The cost of insurance is generally associated with the perceived risk of spill occurrence, which in turn depends on company operational procedures. Consequently, the incentive for oil producers to avoid oil spills is substantial.

The likelihood of an oil spill occurring is expected to be low. The record of platform related oil spills in Australia is generally good, with the exception of the Montara spill (APPEA 2014b). Indeed, the only "oil spill" in Bass Strait to date after 40 years of operations was the result of a bulk carrier carrying manganese ore which ran aground off Tasmania, spilling fuel oil in the process – totally unrelated to the oil industry (Edgar and Barrett 2000).

Assessing impacts ex post

Assessing the actual impact of any spill *ex pos*t is also not straight forward. The studies considered in the report clearly illustrate that a relatively wide range of approaches have been applied when assessing impacts associated with oil spills. Data limitations mean that assessments of the impact on sectors such as fisheries and aquaculture are often constrained to reliance upon historical value of landings/production data, combined with information on costs if possible, as a baseline against which to compare post-spill observations of the same values. If the necessary information is available baselines and impacts may also be modelled, which potentially allows for a broader range of impacts to be considered and at a variety of levels. These approaches can also have a greater capacity to explicitly incorporate and account for factors that could be concurrently influencing the performance of a resource or industry, making the specific effect of the pollution event easier to identify. Unfortunately, even the more generalised forms of modelling approaches typically have greater data requirements than approaches that undertake more simplistic before-and-after types of assessment. They also require a more comprehensive understanding of the case specific circumstances in each instance and rely upon underlying sets of assumptions that may be questioned if the assessed impacts are used as the basis of a claim for compensation.

The International Petroleum Industry Environmental Conservation Association (IPIECA) – the global oil and gas industry association for environmental and social issues – recommends that the guidelines for estimating compensation claims produced by IOPCF (2008) be followed when assessing fisheries economic impacts (IPIECA 2015). These involve an estimation of the loss of profits as a result of any oil spill, and require fishers seeking compensation to submit evidence of revenue loss and cost savings during the period the fishery was affected, as well as information on fishing activity (revenue, costs, logbooks, etc.) over the preceding three years, and effort undertaken to minimise any losses.

The experiences of the previous theoretical estimates of fisheries impacts suggest that these may differ widely, and may ultimately differ substantially from the compensation paid. However, while "academic" in nature, they provide a first estimate of the potential magnitude of the cost, can identify which sectors may have been most adversely affected, and can also be undertaken relatively soon after the incident. In contrast, the compensation process, while more accurate, may take many years to finalise.

Comparing catch and effort levels in the affected year to previous levels can provide a relatively quick and reasonable approximation of the short term impact, as this would also capture the effects of mitigating behaviour. However, it does not provide information as to how the impacts may persist over the coming years. Ideally, some form of bioeconomic model that captures price changes, stock changes and fleet behavioural change would be best for estimating the short to medium term impacts of an oil spill.

A major difficulty identified in the review of past spills was the lack of appropriate data to estimate the impacts. Most previous studies focused on changes in revenue or quantity landed rather than profits, largely as information on costs was unavailable. South Australian commercial fisheries are fortunate in many respects as detailed economic data have been collected for many years. For aquaculture, which may also be adversely affected, economic data are less available, particularly on cost structures and profitability – both essential factors for determining any economic impacts. Similarly, information on cost structures within the Commonwealth fisheries is also limited, while information on Western Australian fisheries is absent.

The potential impact of any oil spill on markets for the fish products is also poorly understood. For aquaculture species, particularly the molluscs which are filter feeders, a potential pollution event such as an oil spill may have a substantial impact on the price received in addition to any biophysical impacts on their production (Sumaila et al. 2012; Le Bihan *et al.* 2013). While changes in market prices can be readily observed, the actual influence of the oil spill on these may be less obvious. Price dynamics in Australian fisheries is fairly poorly understood. Factors such as exchange rate fluctuations, imports and international production levels, and revised trade agreements can all positively or negatively affect prices. Similarly, price increases due to reduced market supply following a spill may be offset by an adverse consumer response (i.e. reduced demand) and result in a net decline in prices. However, if production increases again before consumers demand increases to previous levels, prices may be further depressed relative to pre-spill levels. This is a major information gap in the analysis of medium term impacts on fisheries.

Management responses to mitigate oil-fisheries interactions

From the review and BBN analysis, key factors influencing the impact of an oil spill were the length of any closure, the ability of fishers to relocate their fishing activity and the resilience of the fishers themselves. These factors can all be influenced by fisheries management.

Fishery area closures are often imposed in areas affected by oil for both fisher safety reasons and to prevent oil-affected catch from entering the market (Upton 2011). How long an area remains closed can have an impact on the final economic impact, not just in terms of the forgone production, but also in terms of market perceptions. Moller *et al*. (1999) criticised the disparity in the response to an oil spill with that of a response to a toxic algal bloom (a red tide). While the latter is potentially lethal to consumers, greater restrictions on production and supply to market are often imposed following an oil spill, giving the mistaken impression that seafood was severely contaminated and unsafe to eat (Moller *et al.* 1999). A more recent analysis suggested that frequency of exposure was a key determinant of risk aversion of consumers, with those exposed to more frequent red tides generally less risk averse than those who are infrequently exposed (Kuhar *et al.* 2009). From this, the relative rarity of an oil spill may result in consumers being more risk averse and responding more strongly to the incidence than the immediate health threat may warrant. This risk aversion may also underlie a hesitancy of managers to re-open areas to fishing.

Protocols were established by the US National Oceanic and Atmospheric Administration (NOAA) for the re-opening of areas to fishing following the Deepwater Horizon based on guidelines established by Yender *et al.* (2002). These included visual assessments, as well as sensory perceptions and chemical tests. Similar protocols do not appear to exist for Australian fisheries, with closing and opening of fisheries “subject to advice on seafood safety” (Australian Maritime Safety Authority 2014). Oil spill contingency plans associated with each development aims to demonstrate the capacity of the oil company to respond to and maintain responsibility for a spill, and to identify when and how the operator will involve stakeholders in a response.

The ability of vessels to move to mitigate the impacts of the oil is largely dependent on the flexibility within the management system as well as physical ability of the vessels to fish elsewhere. Fisheries in the GAB are subject to limited entry, with their licences, quota or statutory fishing rights (depending on the fishery) linked to a particular species, gear, or – in some cases – a particular stock. Extensive fisheries, such as the GAB trawl, can readily find alternative fishing areas during an oil spill, although these alternatives may not be as productive as the affected areas. For many other fisheries, the ability to move may be more limited. This in itself may not be problematic. Collins *et al.* (2003) found that, in many cases, the overall cost of a pollution event may be minimised by preventing vessels moving, as the process of shifting fishing location imposes costs on otherwise unaffected fishers and increases costs to the affected fishers.

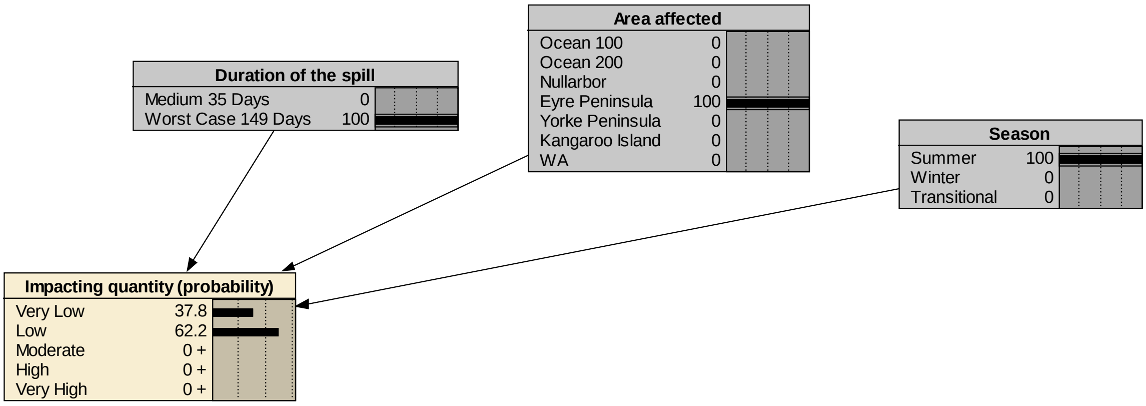
Other mitigating measures

The analyses undertaken in the study assume that there is no oil spill response. In practice, at sea response to stop oil reaching the fisheries may occur, which may substantially reduce the costs imposed on fisheries. The use of dispersants, barriers and mechanical recovery such as surface skimmers can reduce the quantity of oil that may ultimately affect the fisheries. Some studies (e.g. Helle *et al*. 2011; Montewka *et al*. 2013) have found that at sea responses to an oil spill not only reduces the potential impact on fisheries, but are also more cost effective than cleaning up the oil once it reaches the shore.

The effectiveness of these different approaches is highly variable, depending on the prevailing environmental conditions (Helle *et al*. 2011). By assessing the fisheries impacts in the absence of any response, a worst case outcome can be derived. This then provides an upper limit to potential fishery impacts, acknowledging that the actual impacts may be less severe.

APPENDIX A: BBN Conditional Probability Tables

Impacting quantity



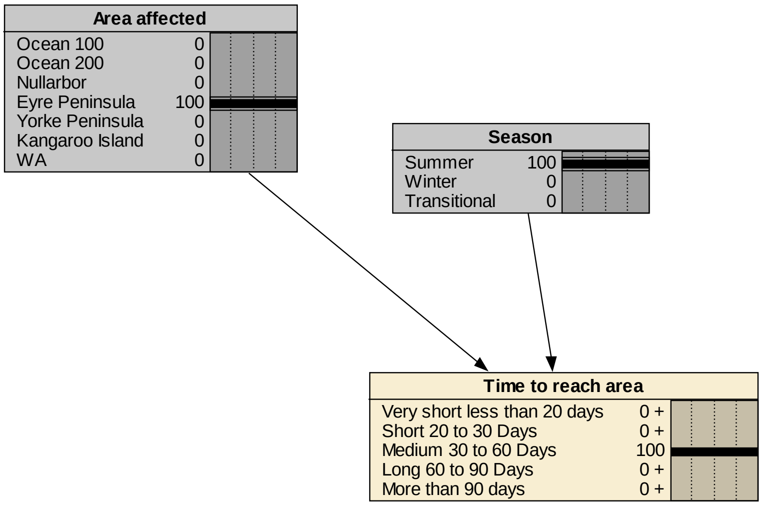
Derived from oil spill modelling output published by BP Developments Australia Pty Ltd (2015a); 2016) using the learning function in NETICA.

Conditional Probability Table

Parent node							
Duration of spill	Area affected	Season	Very Low	Low	Moder-ate	High	Very High
Medium 35 Days	Ocean 100	Sumer	0	0	27	60	13
Medium 35 Days	Ocean 100	Winter	0	0	13	55	32
Medium 35 Days	Ocean 100	Transitional	0	0	19	57	24
Medium 35 Days	Ocean 200	Summer	0	0	24	62	13
Medium 35 Days	Ocean 200	Winter	0	0	13	54	33
Medium 35 Days	Ocean 200	Transitional	0	0	19	56	25
Medium 35 Days	Nullarbor	Summer	100	0	0	0	0
Medium 35 Days	Nullarbor	Winter	100	0	0	0	0
Medium 35 Days	Nullarbor	Transitional	100	0	0	0	0
Medium 35 Days	Eyre Peninsula	Summer	82	18	0	0	0
Medium 35 Days	Eyre Peninsula	Winter	0	100	0	0	0
Medium 35 Days	Eyre Peninsula	Transitional	100	0	0	0	0
Medium 35 Days	Yorke Peninsula	Summer	100	0	0	0	0
Medium 35 Days	Yorke Peninsula	Winter	100	0	0	0	0
Medium 35 Days	Yorke Peninsula	Transitional	100	0	0	0	0
Medium 35 Days	Kangaroo Island	Summer	71	29	0	0	0
Medium 35 Days	Kangaroo Island	Winter	0	35	65	0	0
Medium 35 Days	Kangaroo Island	Transitional	0	74	26	0	0

Parent node							
Duration of spill	Area affected	Season	Very Low	Low	Moder-ate	High	Very High
Medium 35 Days	WA	Summer	100	0	0	0	0
Medium 35 Days	WA	Winter	100	0	0	0	0
Medium 35 Days	WA	Transitional	100	0	0	0	0
Worst Case 149 Days	Ocean 100	Summer	0	0	0	63	37
Worst Case 149 Days	Ocean 100	Winter	0	0	0	0	100
Worst Case 149 Days	Ocean 100	Transitional	0	0	0	22	78
Worst Case 149 Days	Ocean 200	Summer	0	0	0	61	39
Worst Case 149 Days	Ocean 200	Winter	0	0	0	0	100
Worst Case 149 Days	Ocean 200	Transitional	0	0	0	25	75
Worst Case 149 Days	Nullarbor	Summer	100	0	0	0	0
Worst Case 149 Days	Nullarbor	Winter	100	0	0	0	0
Worst Case 149 Days	Nullarbor	Transitional	100	0	0	0	0
Worst Case 149 Days	Eyre Peninsula	Summer	38	62	0	0	0
Worst Case 149 Days	Eyre Peninsula	Winter	23	34	42	0	0
Worst Case 149 Days	Eyre Peninsula	Transitional	16	27	41	16	0
Worst Case 149 Days	Yorke Peninsula	Summer	100	0	0	0	0
Worst Case 149 Days	Yorke Peninsula	Winter	100	0	0	0	0
Worst Case 149 Days	Yorke Peninsula	Transitional	56	44	0	0	0
Worst Case 149 Days	Kangaroo Island	Summer	12	25	40	23	0
Worst Case 149 Days	Kangaroo Island	Winter	18	29	50	3	0
Worst Case 149 Days	Kangaroo Island	Transitional	2	23	36	36	4
Worst Case 149 Days	WA	Summer	34	66	0	0	0
Worst Case 149 Days	WA	Winter	37	63	0	0	0
Worst Case 149 Days	WA	Transitional	100	0	0	0	0

Time for oil to reach each area



Derived from oil spill modelling output published by BP Developments Australia Pty Ltd (2015a); 2016) using the learning function in NETICA.

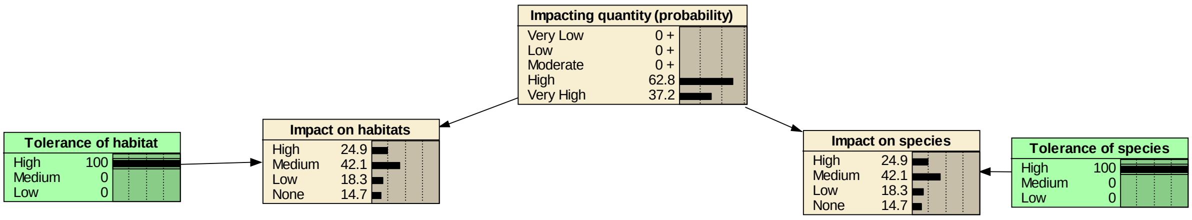
Conditional Probability Table

Parent node		Time to reach area				
Area	Season	<2 Days	20-30 Days	30-60 Days	60-90 Days	>90 Days
Ocean100	Summer	100	0	0	0	0
Ocean100	Winter	100	0	0	0	0
Ocean100	Transitional	100	0	0	0	0
Ocean200	Summer	100	0	0	0	0
Ocean200	Winter	100	0	0	0	0
Ocean200	Transitional	100	0	0	0	0
Nullarbor	Summer	0	0	0	84	16
Nullarbor	Winter	0	0	0	39	61
Nullarbor	Transitional	0	0	0	0	100
Eyre Peninsula	Summer	0	0	100	0	0
Eyre Peninsula	Winter	0	72	28	0	0
Eyre Peninsula	Transitional	0	0	100	0	0
Yorke Peninsula	Summer	0	0	0	0	100
Yorke Peninsula	Winter	0	36	64	0	0
Yorke Peninsula	Transitional	0	0	0	100	0
Kangaroo Island	Summer	0	0	35	65	0
Kangaroo Island	Winter	16	84	0	0	0
Kangaroo Island	Transitional	0	85	15	0	0
Western Australia	Summer	0	100	0	0	0

Parent node		Time to reach area				
Area	Season	<2 Days	20-30 Days	30-60 Days	60-90 Days	>90 Days
Western Australia	Winter	0	0	0	27	73
Western Australia	Transitional	0	0	0	0	100

Impact on species and impact on habitat

Same conditional probability table were assumed for each



Weighting on each parent node (WP)

- Impacting quantity 0.5
- Tolerance 0.5

Assumption: Both the quantity of oil and the tolerance to oil were considered equally important in determining the impact on the species and habitats.

Weight of each level

Parent Node	Level	Weight (WL)
Tolerance	High	0.33
	Medium	0.66
	Low	1.00
Impacting quantity	Very Low	0.10
	Low	0.25
	Medium	0.50
	High	0.75
	Very High	1.00

Algorithm to determine probability of an impacting quantity level (all probabilities sum to 100)

- Pr(High): if any parent node level has a level with weight 1, Pr(High)=sum(WP*WL)*100;
  - else Pr(High)=0
- Pr(Medium): if all parent node levels are greater than 0.33, Pr(Medium)=100-Pr(High);
  - else Pr(Medium)=sum(WP*WL)*(100-Pr(High)
- Pr(Low) = sum(WP*WL)*(100-Pr(High)-Pr(Medium)

- Pr(None) = 100- Pr(High)-Pr(Medium)-Pr(Low)

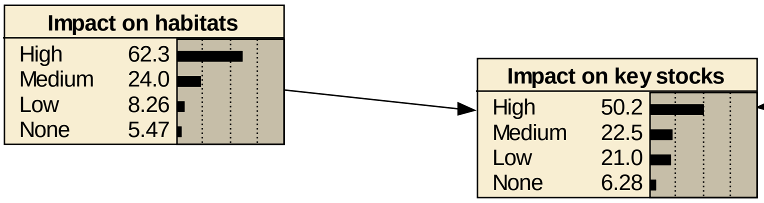
Logic:

- Pr(High): If at least one parent node has a high weight, then the outcome will have some probability of high; if none of the parent nodes have a high weight, then the probability of a high should be zero
- Pr(Medium): if all parent nodes have a medium or high level, then the probability of a low impact is zero, so the probability of a medium is the residual after the probability of a high outcome is calculated; if there is a chance of a Low outcome (due to a low value for a parent node), then the probability of the medium is the weighted impact scaled to100 less the probability of a High
- Pr(Low): the probability of a low is the weighted impact scaled to 100 less the probability of a High and the probability of a Medium
- Pr(None): this is the residual probability. This allows for no impact to occur, although the probability of this is relatively low unless there is no impact on either species of habitats

Conditional Probability Table

Parent node		Species/Habitat impact			
Tolerance	Impacting Quantity	High	Medium	Low	None
High	Very Low	0	22	17	61
High	Low	0	29	21	50
High	Medium	0	42	24	34
High	High	0	54	25	21
High	Very High	67	22	7	4
Medium	Very Low	0	38	24	38
Medium	Low	0	46	25	29
Medium	Medium	0	100	0	0
Medium	High	0	100	0	0
Medium	Very High	83	17	0	0
Low	Very Low	55	25	11	9
Low	Low	63	23	9	5
Low	Medium	75	25	0	0
Low	High	88	12	0	0
Low	Very High	100	0	0	0

Impact on key stocks



Weighting on each parent node (WP)

- Impact on habitat 0.2
- Impact on species 0.8

Assumptions: Direct impact on the species was considered more important in determining the overall impact on the stocks. Habitat damage may result in longer term impacts if critical habitat is irreversibly destroyed, but immediate effects are less likely to be substantial.

Algorithm to determine probability of an impacting quantity level (all probabilities sum to 100)

- Pr(High): if any parent node level has a level with weight 1, Pr(High)=sum(WP*WL)*100;
    - else Pr(High)=0
- Pr(Medium): if all parent node levels are greater than 0.33, Pr(Medium)=100-Pr(High);
    - else Pr(Medium)=sum(WP*WL)*(100-Pr(High)
- Pr(Low) = sum(WP*WL)*(100-Pr(High)-Pr(Medium)
- Pr(None) = 100- Pr(High)-Pr(Medium)-Pr(Low)

Weight of each level

Parent Node	Level	Weight (WL)
Impact on Habitats	High	1.00
	Medium	0.66
	Low	0.33
	None	0
Impact on Species	High	1.00
	Medium	0.66
	Low	0.33
	None	0

Logic:

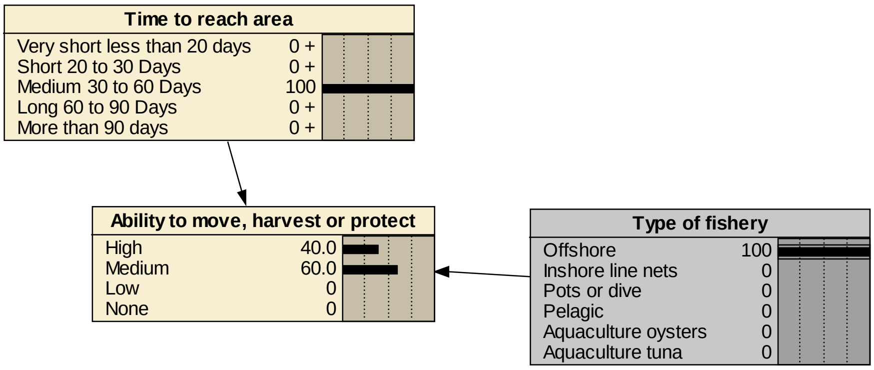
- Pr(High): If at least one parent node has a high weight, then the outcome will have some probability of high; if none of the parent nodes have a high weight, then the probability of a high should be zero

- Pr(Medium): if all parent nodes have a medium or high level, then the probability of a low impact is zero, so the probability of a medium is the residual after the probability of a high outcome is calculated; if there is a chance of a Low outcome (due to a low value for a parent node), then the probability of the medium is the weighted impact scaled to100 less the probability of a High
- Pr(Low): the probability of a low is the weighted impact scaled to 100 less the probability of a High and the probability of a Medium
- Pr(None): this is the residual probability. This allows for no impact to occur, although the probability of this is relatively low unless there is no impact on either species of habitats

Conditional Probability Table

Parent Node		Impact on Key Stocks			
Habitats	Species	High	Medium	Low	None
High	High	100	0	0	0
High	Medium	73	27	0	0
High	Low	46	25	29	0
High	None	20	16	13	51
Medium	High	93	7	0	0
Medium	Medium	0	100	0	0
Medium	Low	0	40	60	0
Medium	None	0	13	11	76
Low	High	87	11	2	0
Low	Medium	0	59	41	0
Low	Low	0	33	67	0
Low	None	0	7	6	87
None	High	80	16	3	1
None	Medium	0	53	25	22
None	Low	0	26	20	54
None	None	0	0	0	100

Ability to move, harvest or protect



Weight of each level

Parent Node	Level	Weight (WL)
Time to reach each area	0-20 Days	0.10
	20-30 Days	0.20
	30-60 Days	0.40
	60-90 Days	0.70
	>90 Days	1.00
Type of fishery	Offshore	1.00
	Inshore (line, nets)	0.20
	Pots, dive	0.10
	Pelagic	1.00
	Aquaculture oysters	0.50
	Aquaculture SBT	0.60

Assumptions: Offshore boats are highly mobile so can move away from oil affected areas; inshore boats have some ability to move, but are generally more limited in their range; potting and dive boats are more limited in where they can fish (informal home patches) and all stocks are at their upper limits; pelagic boats are also generally mobile; oyster farmers can potentially harvest standing stocks provided sufficient notice (although these are likely to be smaller than their optimal size) or implement some form of barrier protection to reduce impacts (at a cost); SBT farmers may have the potential to move some of their cages further down the Gulf or install barrier protection provided sufficient time is available.

Algorithm to determine ability to move, harvest or protect (all probabilities sum to 100)

- Pr(High): Pr(High)= (WL(time)*WL(type)*100;
- Pr(Medium): Pr(Medium)= WL(type)*(100-Pr(High):

- Pr(Low) = WL(type)*(100-Pr(High)-Pr(Medium)
- Pr(None) = 100- Pr(High)-Pr(Medium)-Pr(Low)

Logic:

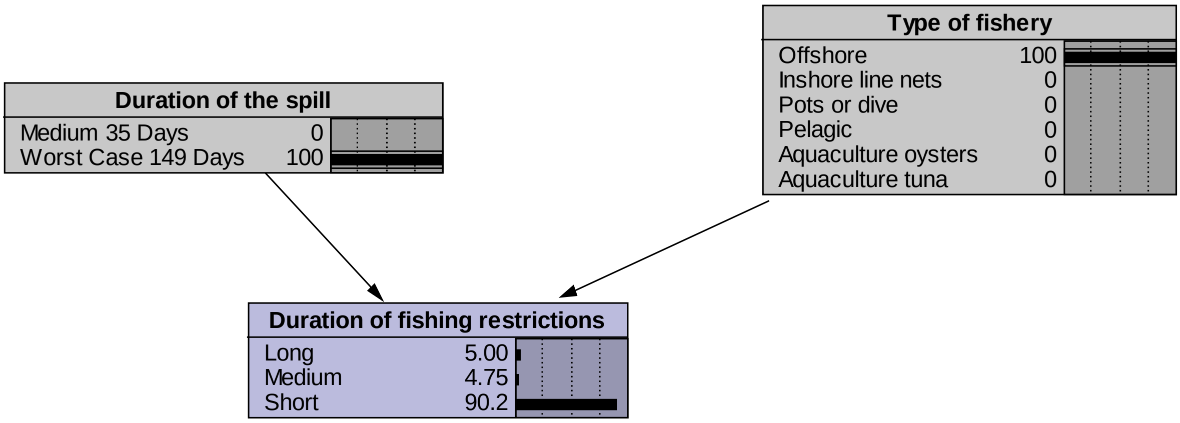
- Pr(High): The ability to harvest depends on the mobility (WL(type)) and time available (WL(time));
- Pr(Medium): As above, but applied to the residual
- Pr(Low): As above, but applied to the residual
- Pr(None): this is the residual probability.

Conditional Probability Table

Parent Node		Ability to move, harvest or protect			
Time	Type	High	Medium	Low	None
0-20 Days	Offshore	10	90	0	0
0-20 Days	Inshore (line, nets)	2	20	16	63
0-20 Days	Pots, dive	1	10	9	80
0-20 Days	Pelagic	10	90	0	0
0-20 Days	Aquaculture oysters	5	48	24	24
0-20 Days	Aquaculture SBT	6	56	23	15
20-30 Days	Offshore	20	80	0	0
20-30 Days	Inshore (line, nets)	4	19	15	61
20-30 Days	Pots, dive	2	10	9	79
20-30 Days	Pelagic	20	80	0	0
20-30 Days	Aquaculture oysters	10	45	23	23
20-30 Days	Aquaculture SBT	12	53	21	14
30-60 Days	Offshore	40	60	0	0
30-60 Days	Inshore (line, nets)	8	18	15	59
30-60 Days	Pots, dive	4	10	9	78
30-60 Days	Pelagic	40	60	0	0
30-60 Days	Aquaculture oysters	20	40	20	20
30-60 Days	Aquaculture SBT	24	46	18	12
60-90 Days	Offshore	70	30	0	0
60-90 Days	Inshore (line, nets)	14	17	14	55
60-90 Days	Pots, dive	7	9	8	75
60-90 Days	Pelagic	70	30	0	0
60-90 Days	Aquaculture oysters	35	33	16	16
60-90 Days	Aquaculture SBT	42	35	14	9
>90 Days	Offshore	100	0	0	0
>90 Days	Inshore (line, nets)	20	16	13	51

>90 Days	Pots, dive	10	9	8	73
>90 Days	Pelagic	100	0	0	0
>90 Days	Aquaculture oysters	50	25	13	13
>90 Days	Aquaculture SBT	60	24	10	6

Duration of fishing restrictions



Weight of each level

Parent Node	Level	Weight (WL)
Duration of the spill	35 Days	0.50
	149 Days	1.00
Type of fishery	Offshore	0.05
	Inshore (line, nets)	0.50
	Pots, dive	0.60
	Pelagic	0.10
	Aquaculture oysters	0.90
	Aquaculture SBT	0.50

Assumptions: The weight for each fishery is associated with the market sensitivity to the product. Offshore boats are more likely to move away from oil affected areas, so their catch will be less affected by the oil (SBT boats supply the aquaculture industry so no real "market" affect). Inshore boats catches are likely to be more affected, and oil is likely to persist longer in the area. Similarly, lobster and abalone boats are in more shallow waters, with export markets potentially affected by risk of contamination (so longer closures to protect the remainder of the industry). Experiences elsewhere have found strong consumer concerns about oyster contamination (McCrea-Strub et al. 2011) and as these are likely to be physically affected by oil there are likely to be longer closures. Even if the stock could be replaced with new uncontaminated spat immediately, there would be

delays before a new harvest was ready. Similarly for ranched SBT, the valuable sashimi market is likely to respond negatively to potential contamination, so bans on harvest are likely to be in place for some time (but assume less than oysters, and more like inshore fish). As the existence of oil (rather than the absolute quantity of oil) is likely to affect the time the fishery is closed, a smaller spill will not be proportionally less than a larger spill (i.e. assume it is only half as long even through the smaller spill is only a quarter of the duration of the larger spill).

Algorithm to determine ability to move, harvest or protect (all probabilities sum to 100)

- Pr(Long): Pr(Long)= (WL(time)*WL(type)*100;
- Pr(Medium): Pr(Medium)= WL(type)*(100-Pr(Long):
- Pr(Short) = (100-Pr(Long)-Pr(Medium)

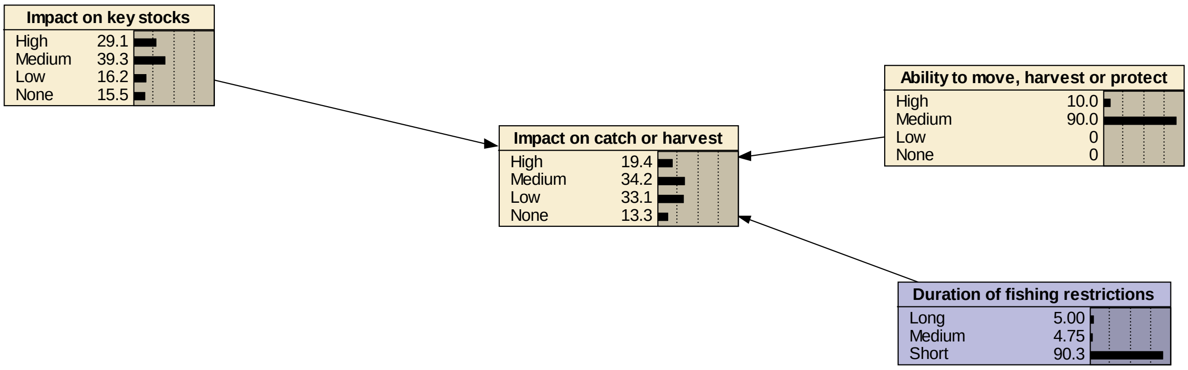
Logic:

- Pr(Long): The length of the restrictions depends on the likely market response (WL(type)) and duration of the spill (WL(time));
- Pr(Medium): As above, but applied to the residual
- Pr(Short): this is the residual probability.

Conditional Probability Table

Parent Node		Duration of fishing restrictions		
Time	Type	Long	Medium	Short
35 Days	Offshore	3	5	93
35 Days	Inshore (line, nets)	25	38	38
35 Days	Pots, dive	30	42	28
35 Days	Pelagic	5	10	86
35 Days	Aquaculture oysters	45	50	6
35 Days	Aquaculture SBT	25	38	38
149 Days	Offshore	5	5	90
149 Days	Inshore (line, nets)	50	25	25
149 Days	Pots, dive	60	24	16
149 Days	Pelagic	10	9	81
149 Days	Aquaculture oysters	90	9	1
149 Days	Aquaculture SBT	50	25	25

Impact on catch



Weighting on each parent node (WP)

- Impact on key stocks 0.5
- Ability to move 0.25
- Duration of fishing restrictions 0.25

Assumptions: Stocks are a key driver of catch rates (and hence catch), while fishing restrictions (area closures) also physically prevent catching; however, both may be mitigated to some extent by moving to a different fishing area.

Weight of each level

Parent Node	Level	Weight (WL)
Impact on key stocks	High	1.00
	Medium	0.66
	Low	0.33
	None	0
Ability to move	High	0
	Medium	0.33
	Low	0.66
	None	1.00
Duration of fishing restrictions	Long	1.00
	Medium	0.66
	Short	0.33

Algorithm to determine probability of an impacting quantity level (all probabilities sum to 100)

- Pr(High): if ability to move =0, Pr(High)=0;
  - else if any parent node level has a level with weight 1, Pr(High)=sum(WP*WL)*100;
  - else Pr(High)=0

- Pr(Medium): if all parent node levels are greater than 0.33, Pr(Medium)=100-Pr(High);
    - else Pr(Medium)=sum(WP*WL)*(100-Pr(High)
- Pr(Low) = sum(WP*WL)*(100-Pr(High)-Pr(Medium)
- Pr(None) = 100- Pr(High)-Pr(Medium)-Pr(Low)

Logic:

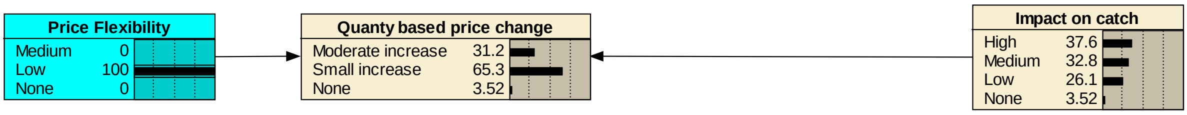
- Pr(High): If boats are able to move, then the impact on catches will be less than high; Otherwise, if at least one parent node has a high weight, then the outcome will have some probability of high; if none of the parent nodes have a high weight, then the probability of a high should be zero
- Pr(Medium): if all parent nodes have a medium or high level, then the probability of a low impact is zero, so the probability of a medium is the residual after the probability of a high outcome is calculated; if there is a chance of a Low outcome (due to a low value for a parent node), then the probability of the medium is the weighted impact scaled to100 less the probability of a High
- Pr(Low): the probability of a low is the weighted impact scaled to 100 less the probability of a High and the probability of a Medium
- Pr(None): this is the residual probability. This allows for no impact to occur, although the probability of this is relatively low unless there is no impact on either species of habitats

Conditional Probability Table

Parent Node			Impact on Catch			
Impact on key stocks	Duration of restrictions	Ability to move	High	Medium	Low	None
High	Long	High	0	75	19	6
High	Long	Medium	83	14	3	0
High	Long	Low	92	8	0	0
High	Long	None	100	0	0	0
High	Medium	High	0	67	22	11
High	Medium	Medium	75	19	6	0
High	Medium	Low	83	17	0	0
High	Medium	None	92	8	0	0
High	Short	High	0	58	24	18
High	Short	Medium	67	22	11	0
High	Short	Low	75	19	6	0
High	Short	None	83	14	3	0
Medium	Long	High	0	58	24	18
Medium	Long	Medium	66	23	11	0
Medium	Long	Low	75	25	0	0
Medium	Long	None	83	17	0	0
Medium	Medium	High	0	50	25	25

Parent Node			Impact on Catch			
Impact on key stocks	Duration of restrictions	Ability to move	High	Medium	Low	None
Medium	Medium	Medium	0	58	42	0
Medium	Medium	Low	0	100	0	0
Medium	Medium	None	75	25	0	0
Medium	Short	High	0	41	24	35
Medium	Short	Medium	0	50	50	0
Medium	Short	Low	0	58	42	0
Medium	Short	None	66	23	11	0
Low	Long	High	0	42	24	34
Low	Long	Medium	50	25	25	0
Low	Long	Low	58	24	18	0
Low	Long	None	67	22	11	0
Low	Medium	High	0	33	22	45
Low	Medium	Medium	0	41	59	0
Low	Medium	Low	0	50	50	0
Low	Medium	None	58	24	18	0
Low	Short	High	0	25	19	56
Low	Short	Medium	0	33	67	0
Low	Short	Low	0	41	59	0
Low	Short	None	50	25	25	0
None	Long	High	0	25	19	56
None	Long	Medium	0	33	22	45
None	Long	Low	0	42	24	34
None	Long	None	0	50	25	25
None	Medium	High	0	17	14	69
None	Medium	Medium	0	25	19	56
None	Medium	Low	0	33	22	45
None	Medium	None	0	42	24	34
None	Short	High	0	8	8	84
None	Short	Medium	0	17	14	69
None	Short	Low	0	25	19	56
None	Short	None	0	33	22	45

Quantity induced price changes



Weighting on each parent node (WP)

- Impact on catch 0.5
- Price flexibility 0.5

Assumptions: Price changes are equally a result of quantity change and price flexibility.

Weight of each level

Parent Node	Level	Weight (WL)
Impact on catch	High	1
	Medium	0.66
	Low	0.33
	None	0
Price Flexibility	Medium	1.00
	Low	0.66
	None	0.33

Algorithm to determine probability of anprice level (all probabilities sum to 100)

- Pr(High): if price flexibility =0, Pr(High)=0;
    - else if catch = 0, Pr(High)=0;
    - else if any parent node level has a level with weight 1, Pr(High)=sum(WP*WL)*100;
    - else Pr(High)=0
- Pr(Medium): if price flexibility =0, Pr(Medium)=0;
    - else if catch = 0, Pr(Medium)=0;
    - else Pr(Medium)=sum(WP*WL)*(100-Pr(High)
- Pr(None) = 100- Pr(High)-Pr(Medium)

Logic:

- Pr(Moderate increase): If price flexibility is zero then prices will not change even if quantity landed changes; if catch does not change then prices will not change; Otherwise, if at least one parent node has a high weight, then the outcome will have some probability of a moderate increase; if none of the parent nodes have a high weight, then the probability of a moderate increase should be zero
- Pr(Small increase): If price flexibility is zero then prices will not change even if quantity landed changes; if catch does not change then prices will not change; if all parent nodes have a medium or high level, then the probability of no impact is zero, so the probability of a small

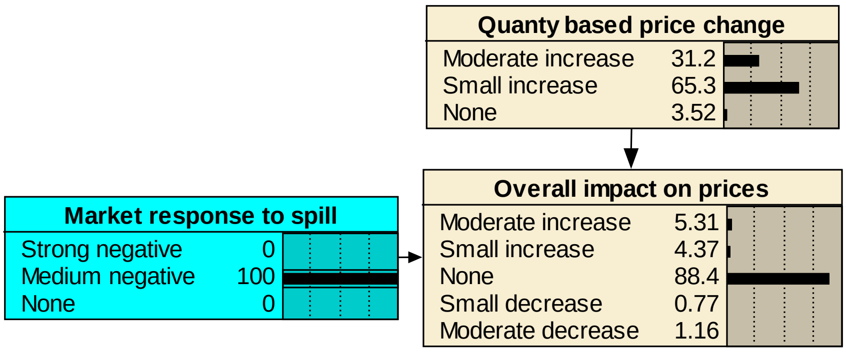
increase is the residual after the probability of a moderate increase outcome is calculated; if there is a chance of a small increase outcome (due to a low value for a parent node), then the probability of the small increase is the weighted impact scaled to100 less the probability of a moderate increase

- Pr(None): this is the residual probability. This allows for no price impact to occur.

Conditional Probability Table

Parent Node		Quantity based price change		
Price Flexibility	Impact on catch	Moderate increase	Small increase	None
Medium	High	100	0	0
Medium	Medium	83	17	0
Medium	Low	67	33	0
Medium	None	0	0	100
Low	High	83	17	0
Low	Medium	0	100	0
Low	Low	0	100	0
Low	None	0	0	100
None	High	0	0	100
None	Medium	0	0	100
None	Low	0	0	100
None	None	0	0	100

Overall impact on prices



Weighting on each parent node (WP)

- Quantity based price change 0.5
- Market response to spill 0.5

Assumptions: Market response will be negative (if any) while production based responses will be positive (if any). Both are assumed to have an equal impact on overall price, which may be either a net increase or net decrease in prices.

Weight of each level

Parent Node	Level	Weight (WL)
Quantity based price change	Moderate increase	1.00
	Small increase	0.66
	None	0
Market response to spill	Strong negative	-1.00
	Medium negative	-0.66
	None	1

Algorithm to determine probability of overall impact on prices (all probabilities sum to 100)

- Pr(Moderate increase): if the sum of the levels >0, Pr(Moderate increase)=sum(WP*WL)*100;
  - else Pr(Moderate increase)=0;
- Pr(Small increase): if the sum of the levels >0, Pr(Small increase)=sum(WP*WL)*(100-Pr(Moderate increase);
  - else Pr(Small increase)=0;
- Pr(Moderate decrease): if the sum of the levels <0, Pr(Moderate decrease)=sum(WP*WL)*100;
  - else Pr(Moderate decrease)=0;
- Pr(Small decrease) = if the sum of the levels <0, Pr(Small decrease)=sum(WP*WL)*(100-Pr(Moderate decrease);
  - else Pr(Moderate decrease)=0;
- Pr(None) = 100- Pr(Moderate increase)-Pr(Small increase)-Pr(Moderate decrease)- Pr(Small decrease)

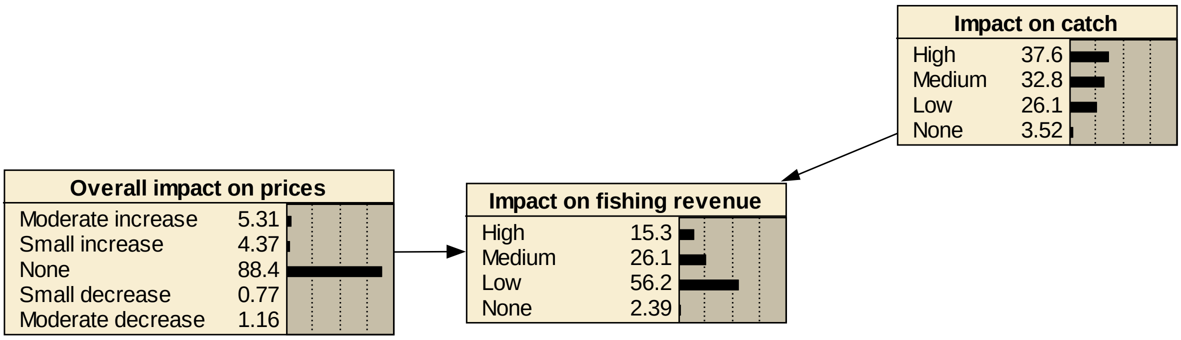
Logic:

- Pr(Moderate increase): If the positive quantity effect is larger than the negative effect, then some increase is expected. The probability of the moderate increase will depend on the relative strengths on the individual price effects. If the positive quantity effect is smaller than the negative effect, then the probability of any increase is zero;
- Pr(Small increase): As with the moderate increase, this can only occur if the quantity effect is larger than the negative market effect; and is proportional to the relative strengths of these effects and how much of the probability has already been taken up by the moderate increase;
- Pr(Moderate decrease) and Pr(small decrease): these are the opposite to the moderate increase and small increase
- Pr(None): this is the residual probability once the other probabilities have been calculated.

Conditional Probability Table

Parent node		Overall impact on prices				
Market response	Quantity induced prices	Moderate increase	Small increase	None	Small decrease	Moderate decrease
Strong negative	Moderate increase	0	0	100	0	0
Strong negative	Small increase	0	0	69	14	17
Strong negative	None	0	0	25	25	50
Medium negative	Moderate increase	17	14	69	0	0
Medium negative	Small increase	0	0	100	0	0
Medium negative	None	0	0	45	22	33
None	Moderate increase	50	25	25	0	0
None	Small increase	33	22	45	0	0
None	None	0	0	100	0	0

Impact on fishing revenue



Weighting on each parent node (WP)

- Overall impact on prices 0.5
- Impact on catch 0.5

Assumptions: Price and quantity changes equally affect fishing revenue.

Weight of each level

Parent Node	Level	Weight (WL)
Overall impact on prices	Moderate increase	-1.00
	Small increase	-0.66
	None	0
	Small decrease	0.66
	Moderate decrease	1.00

Parent Node	Level	Weight (WL)
Impact on catch	High	1.00
	Medium	0.66
	Low	0.33
	None	0

Algorithm to determine probability of overall impact on prices (all probabilities sum to 100)

- Pr(High): if catch or price impacts =1, Pr(High)=sum(WP*WL)*100;
  - else Pr(High)=0;
- Pr(Medium): if catch impact >0.33, Pr(medium)=sum(WP*ABS(WL))*(100-Pr(High));
  - else Pr(Medium)=0;
- Pr(Low): if catch impact >0, Pr(Low)= sum(WP*ABS(WL))*(100-Pr(High)-Pr(Medium);
  - else Pr(Low)=0;
- Pr(None) = 100- Pr(High)-Pr(Medium)-Pr(Low)

Logic:

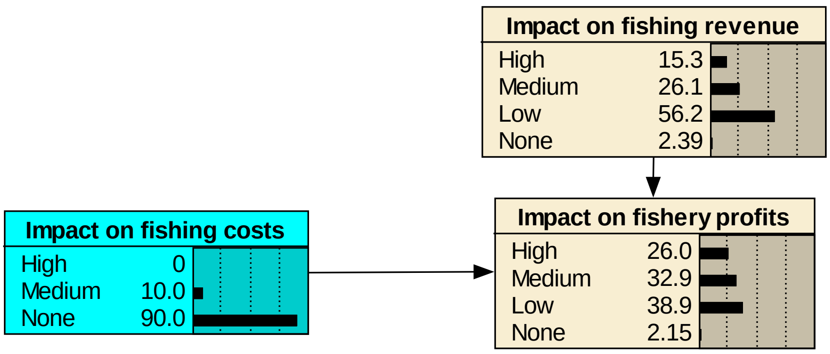
- Pr(High): A large catch decrease, or a large price decrease, will result in a high impact (decrease) in revenue. If neither price nor catch changes are high, then the probability of a high impact on fishing revenue is zero;
- Pr(Medium): As moderate decrease in catch will result in a moderate decrease in revenue even if prices increase;
- Pr(Low) If the change in catch is low then some impact on revenue is expected.
- Pr(None): this is the residual probability once the other probabilities have been calculated. It is only equal to 100 when catch is zero.

Conditional Probability Table

Parent Node		Impact on fishing revenue			
Overall impact on prices	Impact on catch	High	Medium	Low	None
Moderate increase	High	0	100	0	0
Moderate increase	Medium	0	83	17	0
Moderate increase	Low	0	0	100	0
Moderate increase	None	0	0	0	100
Small increase	High	17	69	14	0
Small increase	Medium	0	66	34	0
Small increase	Low	0	0	100	0
Small increase	None	0	0	0	100
None	High	50	25	25	0
None	Medium	0	33	67	0

Parent Node		Impact on fishing revenue			
Overall impact on prices	Impact on catch	High	Medium	Low	None
None	Low	0	0	100	0
None	None	0	0	0	100
Small decrease	High	83	14	3	0
Small decrease	Medium	0	66	34	0
Small decrease	Low	0	0	100	0
Small decrease	None	0	0	33	67
Moderate decrease	High	100	0	0	0
Moderate decrease	Medium	83	14	3	0
Moderate decrease	Low	67	0	33	0
Moderate decrease	None	50	0	25	25

Impact on fishery profits



Weighting on each parent node (WP)

- Impact on fishing revenue 0.7
- Impact on fishing costs 0.3

Assumptions: Pascoe and Innes (2017) found that the profitability of the fisheries in the GAB are more sensitive to changes in revenue than changes in cost.

Weight of each level

Parent Node	Level	Weight (WL)
Impact on fishing revenue	High	1.00
	Medium	0.66
	Low	0.33
	None	0

Parent Node	Level	Weight (WL)
Impact on fishing costs	High	1.00
	Medium	0.66
	None	0

Algorithm to determine probability of overall impact on profits (all probabilities sum to 100)

- Pr(High): if revenue impacts >0.33, Pr(High)=sum(WP*WL)*100;
    - else Pr(High)=0;
- Pr(Medium): if revenue impact >0.33, Pr(medium)= 100-Pr(High);
    - else Pr(medium)=sum(WP*WL)*(100-Pr(High));
- Pr(Low): if revenue impact >0, Pr(Low)= (100-Pr(High)-Pr(Medium);
    - else Pr(Low)= sum(WP*WL)*(100-Pr(High)-Pr(Medium);
- Pr(None) = 100- Pr(High)-Pr(Medium)-Pr(Low)

Logic:

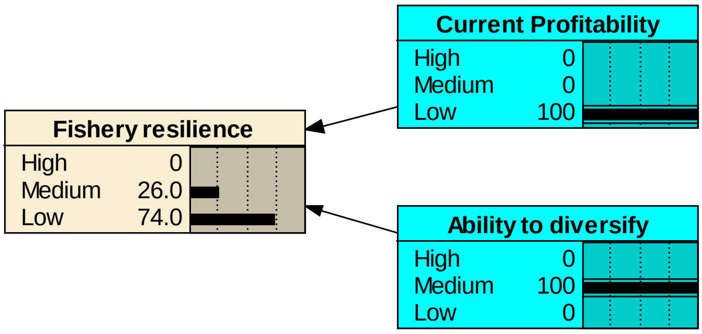
- Pr(High): A medium or large revenue decrease, will result in some high impact (decrease) in profits. A low or zero revenue change will result in a low or medium decrease in profits;
- Pr(Medium): A moderate decrease in revenue will result in at least a moderate decrease in profits even if costs do not increase;
- Pr(Low) If the change in revenue is low then at least some impact on revenue is expected.
- Pr(None): this is the residual probability once the other probabilities have been calculated. It is only equal to 100 when both revenue and cost change is zero.

Conditional Probability Table

Parent Node		Impact on fishery profits			
Impact on revenue	Impact on costs	High	Medium	Low	None
High	High	100	0	0	0
High	Medium	90	10	0	0
High	None	70	30	0	0
Medium	High	76	24	0	0
Medium	Medium	66	34	0	0
Medium	None	46	54	0	0
Low	High	0	53	47	0
Low	Medium	0	43	57	0
Low	None	0	23	77	0

Parent Node		Impact on fishery profits			
Impact on revenue	Impact on costs	High	Medium	Low	None
None	High	0	30	21	49
None	Medium	0	20	16	64
None	None	0	0	0	100

Fishery resilience



Weighting on each parent node (WP)

- Current profitability 0.6
- Ability to diversify 0.4

Assumptions: The fishery resilience was assumed to be more dependent on the level of current profitability as this determines the level of reserves that the fishers may have accumulated. The ability to diversity, either by targeting other species or moving their business operations temporarily, will also mitigate some of the short term impacts.

Weight of each level

Parent Node	Level	Weight (WL)
Current profitability	High	1.00
	Medium	0.66
	Low	0
Ability to diversify	High	1.00
	Medium	0.66
	Low	0

Algorithm to determine probability of fishery resilience (all probabilities sum to 100)

- Pr(High): if profitability or ability to diversify >0.66, Pr(High)= sum(WP*WL)*100;
    - else Pr(High)=0;

- Pr(Medium): if both profitability or ability to diversify >0, Pr(medium)= sum(WP*WL)*(100-Pr(High));
    - o else Pr(Medium)=0;
- Pr(Low): 100- Pr(High)-Pr(Medium)

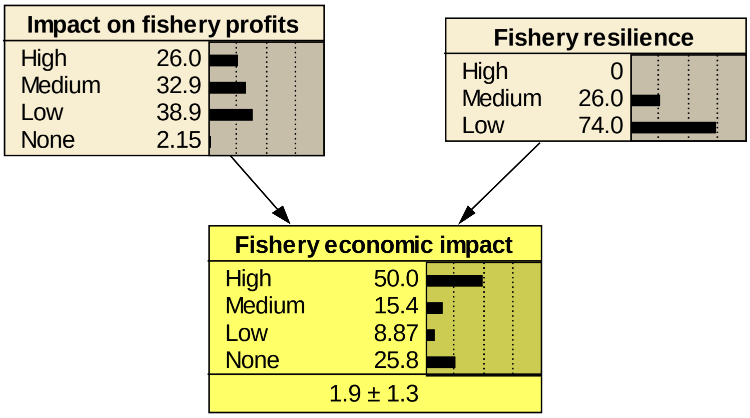
Logic:

- Pr(High): The probability of high resilience requires either profitability or ability to diversify to be high; If neither are high then the probability of resilience being high is zero.
- Pr(Medium): The probability of medium resilience requires either profitability or ability to diversify to be above zero; If neither are above zero then the probability of resilience being high is zero;
- Pr(Low) this is the residual probability once the other probabilities have been calculated. It is only equal to 100 when both profitability and ability to diversify are zero.

Conditional Probability Table

Parent Node		Fishery resilience		
Current Profitability	Ability to diversify	High	Medium	Low
High	High	100	0	0
High	Medium	86	12	2
High	Low	60	24	16
Medium	High	80	16	4
Medium	Medium	0	66	34
Medium	Low	0	40	60
Low	High	40	24	36
Low	Medium	0	26	74
Low	Low	0	0	100

Fishery economic impact



Weighting on each parent node (WP)

- Impact on fishery profits 0.5
- Fishery resilience 0.5

Assumptions: The weights were assumed to be equal. However, the calculation of the overall impact was more influenced by the impact on fishery profits.

Weight of each level

Parent Node	Level	Weight (WL)
Impact on fishery profits	High	1.00
	Medium	0.66
	Low	0.33
	None	0
Fishery resilience	High	0.10
	Medium	0.66
	Low	1.00

Algorithm to determine probability of overall fishery impacts (all probabilities sum to 100)

- Pr(High)= $WL_{profits}$*sum(WP*WL)*100;
- Pr(medium)= $WL_{profits}$*sum(WP*WL)*(100-Pr(High))
- Pr(Low)= $WL_{profits}$*sum(WP*WL)*(100-Pr(High)-Pr(Medium))
- Pr(None): 100- Pr(High)-Pr(Medium)-Pr(Low)

Logic:

- The overall impact is directly linked to changes in fishery profits, although this can be mitigated to some extent by the resilience of the fishery. A fishery with no impacts on profits will have no overall impact. The effects of a high profit impact can be reduced (but not eliminated) by a high resilience.

Conditional Probability Table

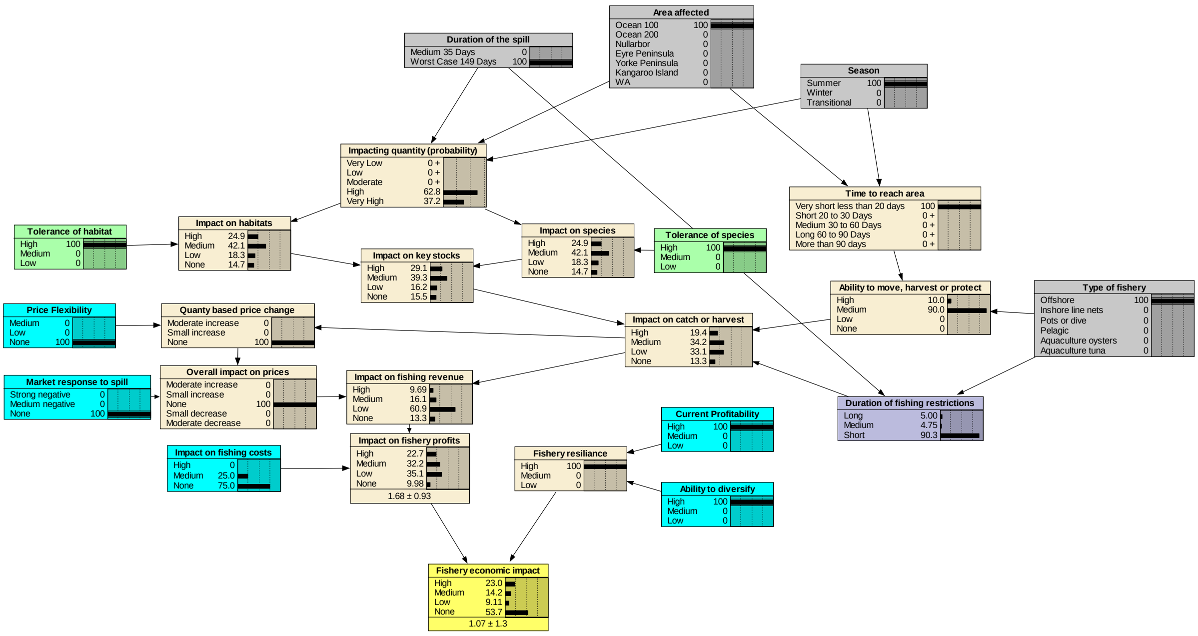
Parent Node		Overall fishery economic impact			
Impact on fishery profits	Fishery resilience	High	Medium	Low	None
High	High	55	25	11	9
High	Medium	83	14	2	1
High	Low	100	0	0	0
Medium	High	25	19	14	42
Medium	Medium	44	24	14	18
Medium	Low	55	25	11	9
Low	High	7	7	6	80
Low	Medium	16	14	11	59
Low	Low	22	17	13	48
None	High	0	0	0	100
None	Medium	0	0	0	100
None	Low	0	0	0	100

APPENDIX B: Fisheries economic impact derived from the BBN

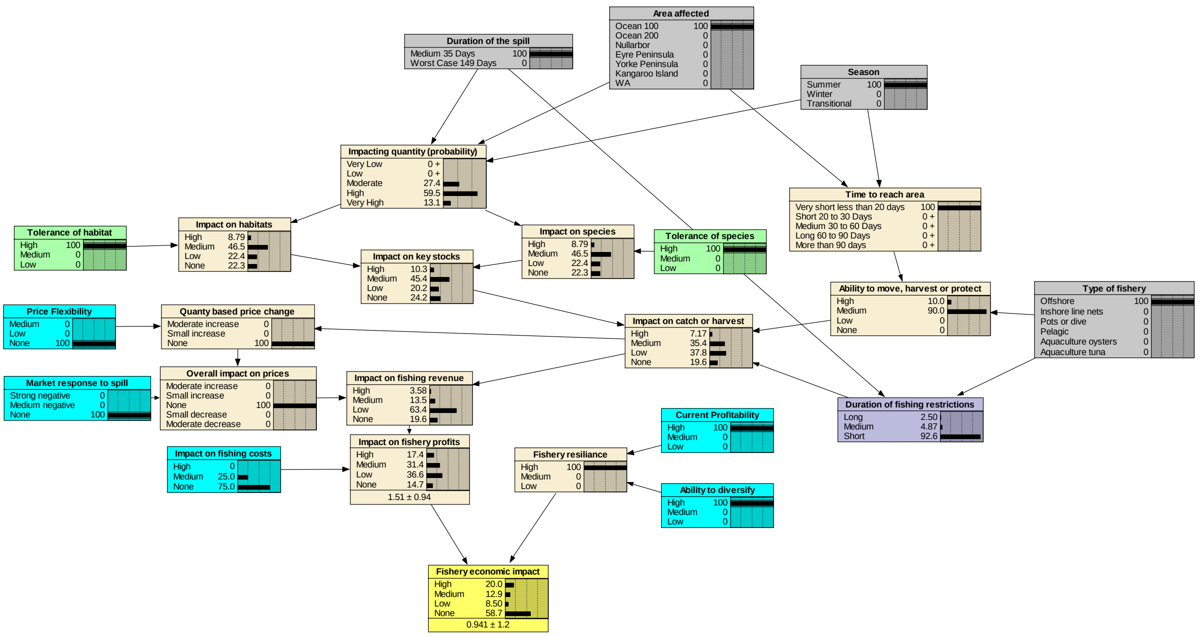
Southern Bluefin Tuna

Assumptions: as stated in the example provided previously.

Large summer spill (149 days)



Medium summer spill (35 days)



As the fishery does not operate in the GAB in the winter, the other seasons were not examined.

Marine scalefish fishery

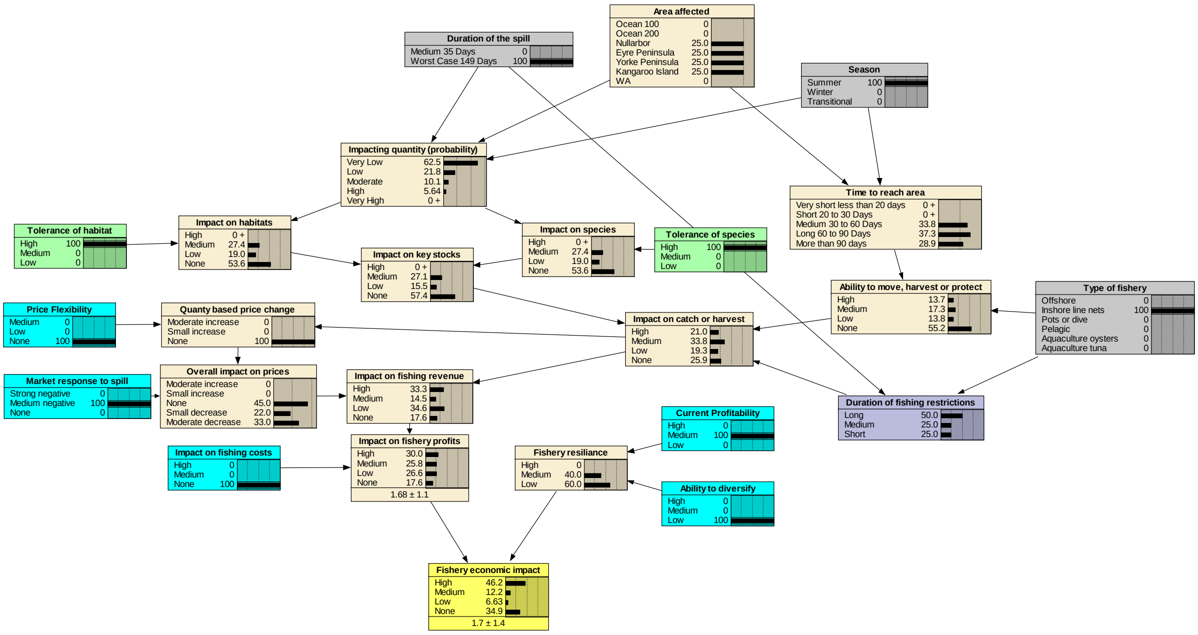
Assumptions: Both the fish species and habitats are highly tolerant to the presence of oil based on the outcomes of the Montara report (Young et al. 2011). The fishers are fairly small scale and are closely tied to the areas in which they fish. While they could potentially move further around the GAB, this is not very likely given their size and dependence on their local ports, and few will be able to feasibly move. Given this, cost changes will be minor.

Most of the fishing activity that is likely to be affected takes place along the Eyre Peninsula, but fishing activity occurs along the whole coast. It was assumed that the distribution was 40% in the Eyre Peninsula, and 20% in each of the other three coastal regions.

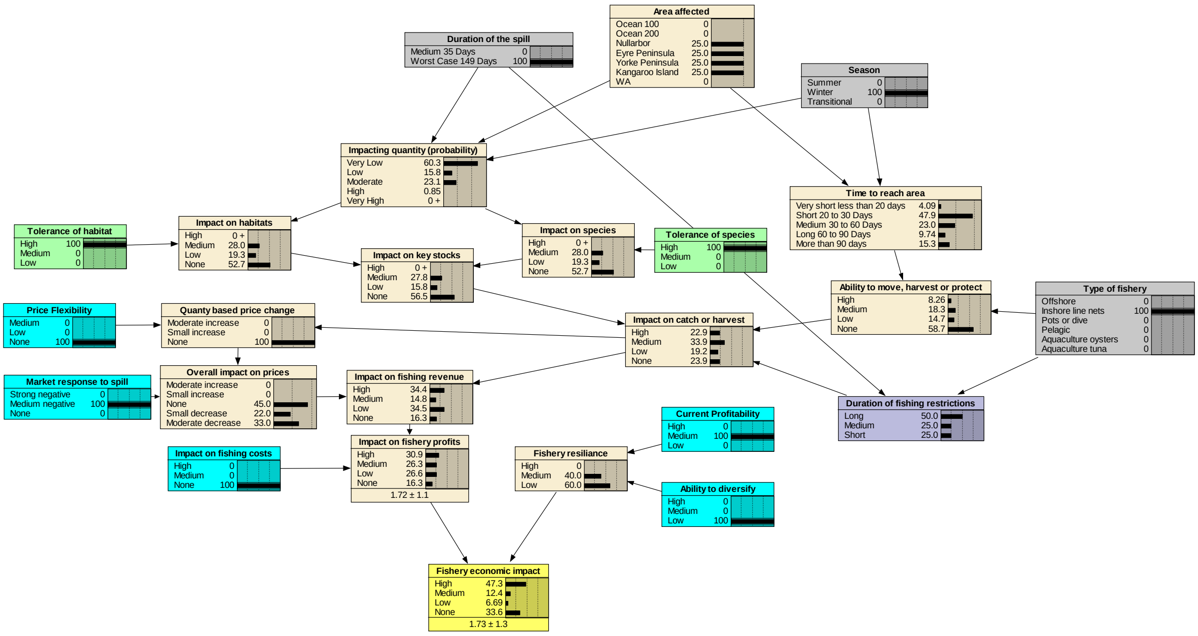
The fleet has a low level of profitability (EconSearch 2015) and a moderate dependence on the fishery for income. Around 50% of fishers rely on the fishery for 75% or more of their household income (Triantafillos *et al.* 2014), so their ability to diversify was considered only medium.

Most of the fish species caught are sold on the local market, most with a generally low price flexibility (Bose 2004). Given that most fish are sold locally, there is the likelihood that there will be some consumer response to the oil spill, with consumers wanting to avoid fish that are potentially contaminated. Studies elsewhere have found substantial (up to 30%) reductions in fish prices immediately following an oil spill (Born et al. 2003). In some cases, prices return to normal levels fairly rapidly (i.e. within a couple of weeks) (Born et al. 2003), while other studies have found prices may take a year or two to fully recover (Sumaila et al. 2012). Given the relatively low level of impact on the stocks, we assume that any market price response will be only moderate and of relatively short duration.

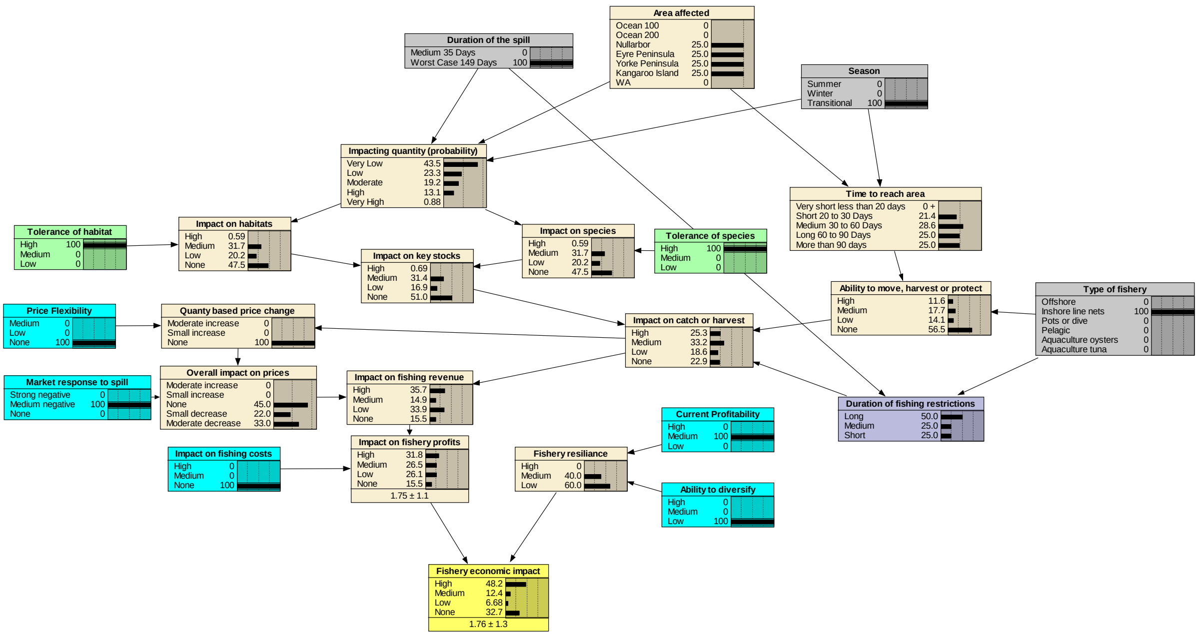
Large summer spill (149 days)



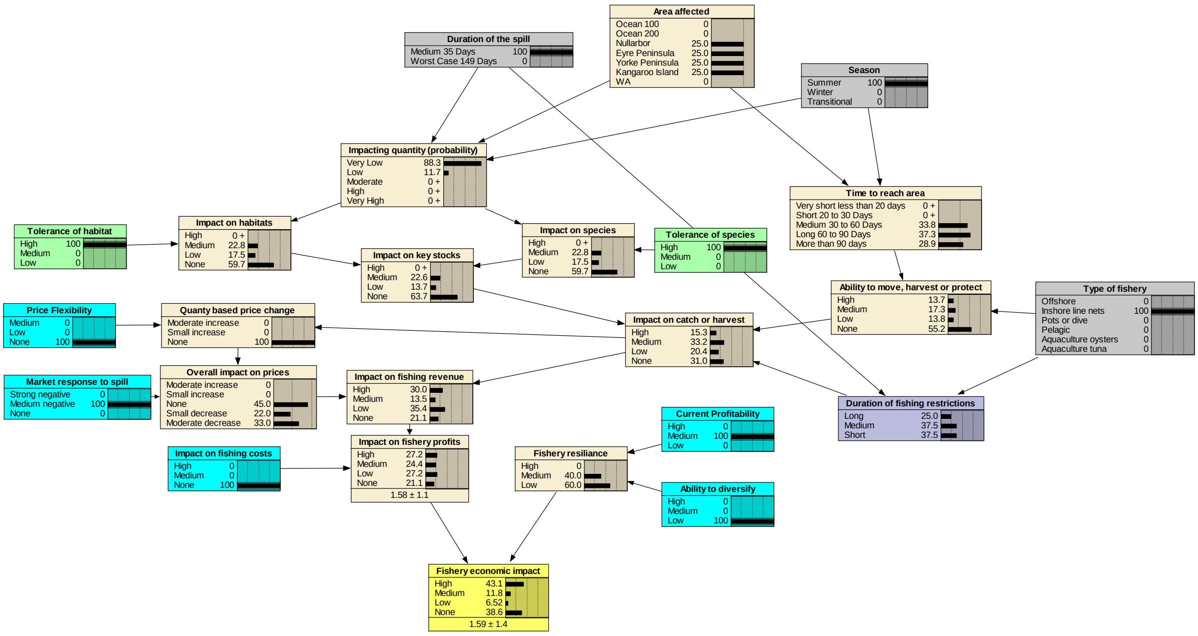
Large winter spill (149 days)



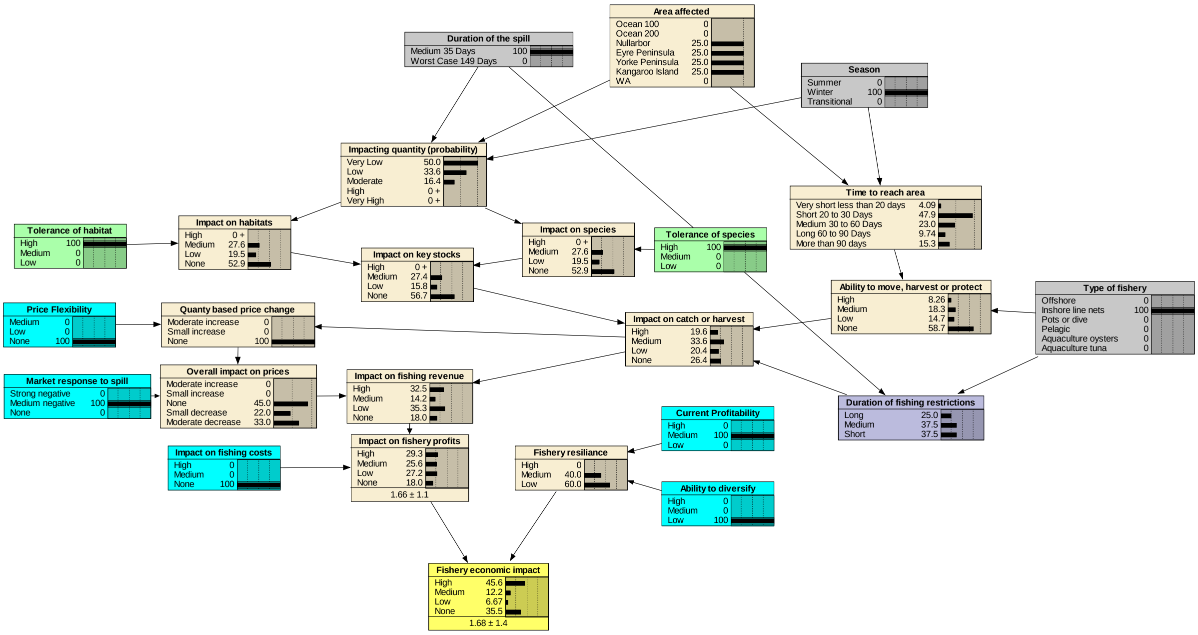
Large transitional season spill (149 days)



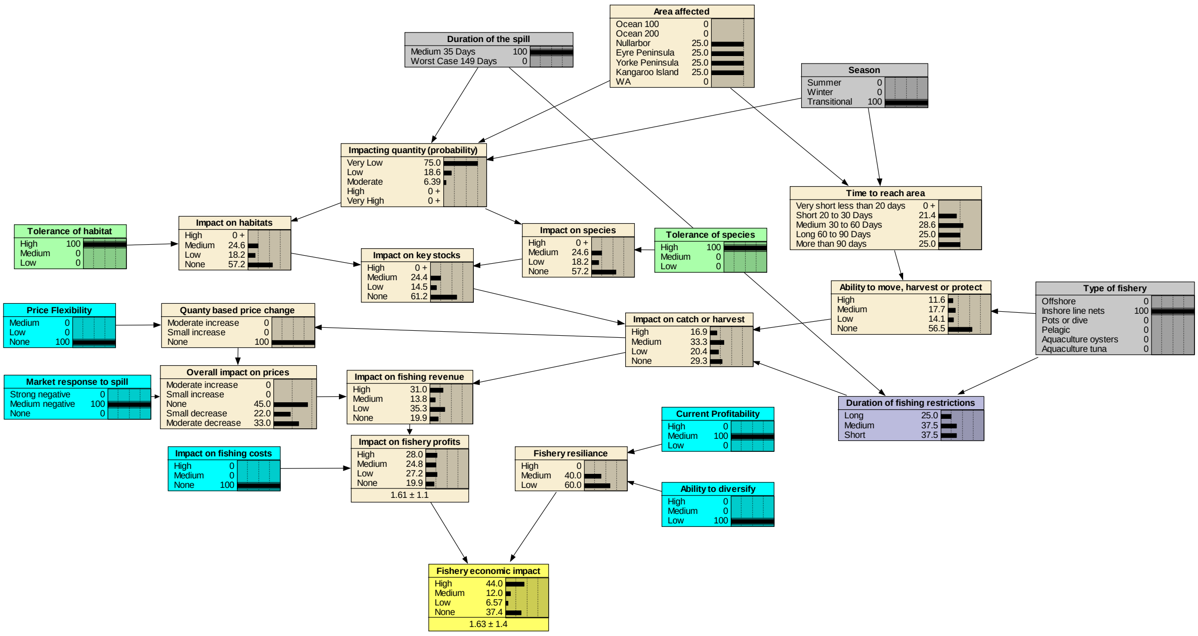
Medium summer spill (35 days)



Medium winter spill (35 days)



Medium transitional season spill (35 days)



Gillnet, Hook and Trap Fishery

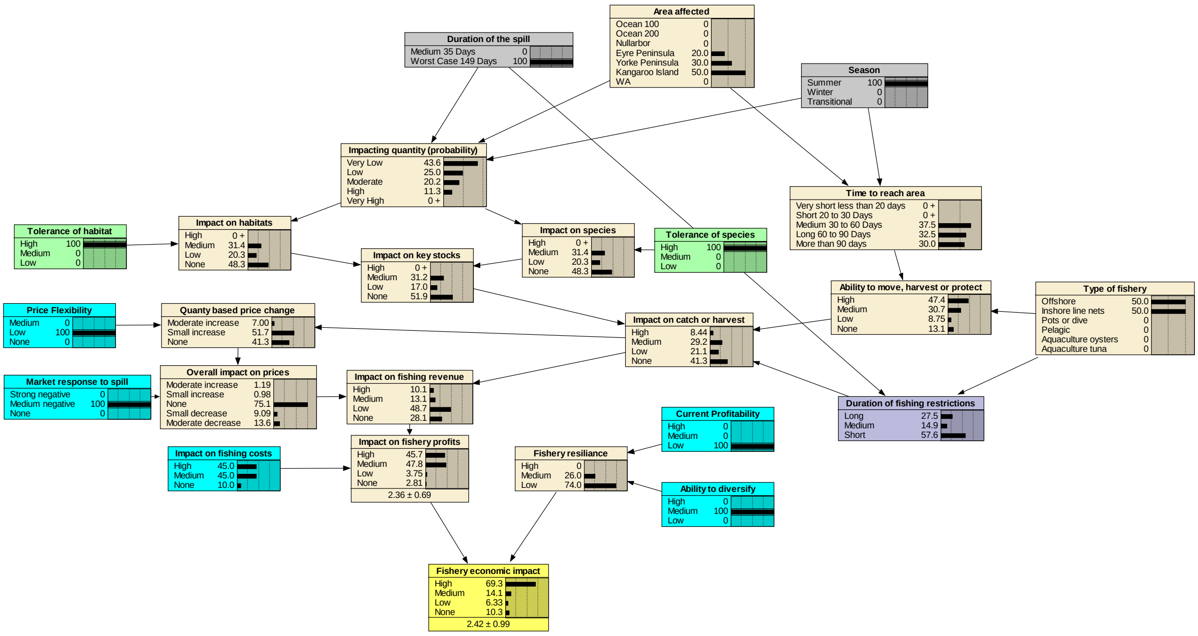
Assumptions: Both the shark species and habitats are highly tolerant to the presence of oil based on the outcomes of the Montara report (Young *et al.* 2011). The fishers are able to fish elsewhere in the South east, and it is likely that they will move to areas further east to avoid the oil. This will have medium to high impacts on their fishing costs.

Most of the fishing activity takes place in the southern and eastern parts of the state, so assumed to be 20% Eyre Peninsula, 30% Yorke Peninsula and 50% Kangaroo Island for the purposes of the analysis. The fishery operates in inshore waters as well as deeper waters, so it was assumed to be 50% offshore and 50% inshore for the purposes of the analysis.

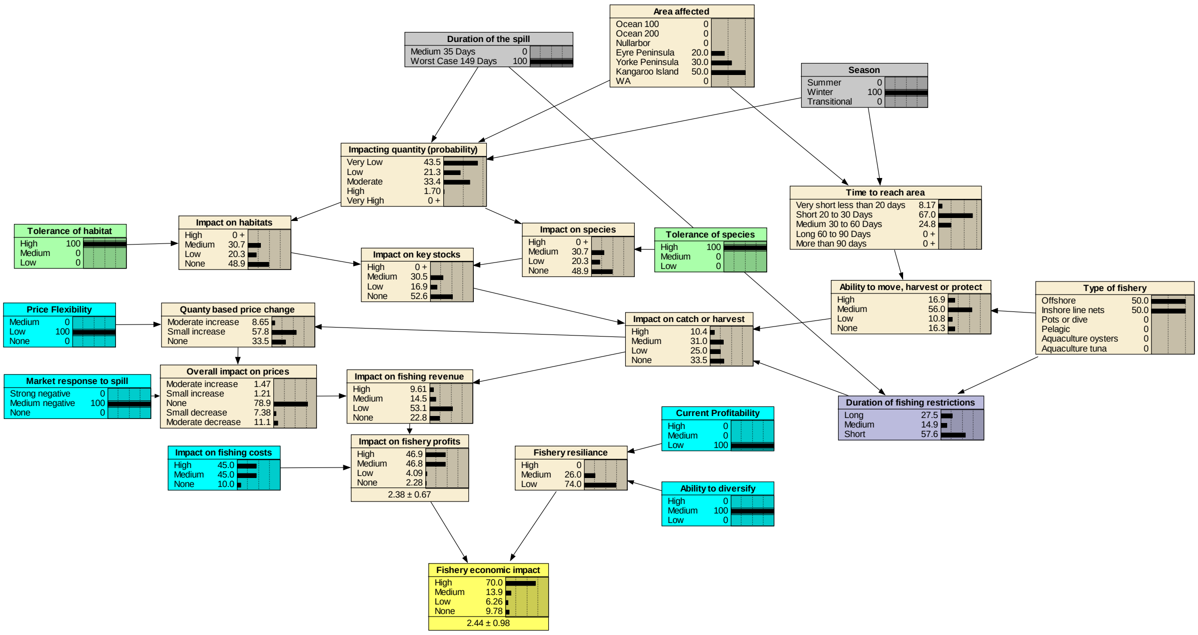
The fleet has a low level of profitability (Skirtun and Green 2015). Many fishers operate using multiple gears (i.e. nets and hooks) so may potentially switch target species to avoid the impacts of the oil.

Most of the shark species caught are sold on the local market, most with a generally low price flexibility (Bose 2004). Given that most shark are sold locally and much of the catch ends up in fish and chip shops, there is the likelihood that there will be some consumer response to the oil spill, with consumers wanting to avoid fish that are potentially contaminated. Given the relatively low level of impact on the stocks, we assume that any market price response will be only moderate and of relatively short duration.

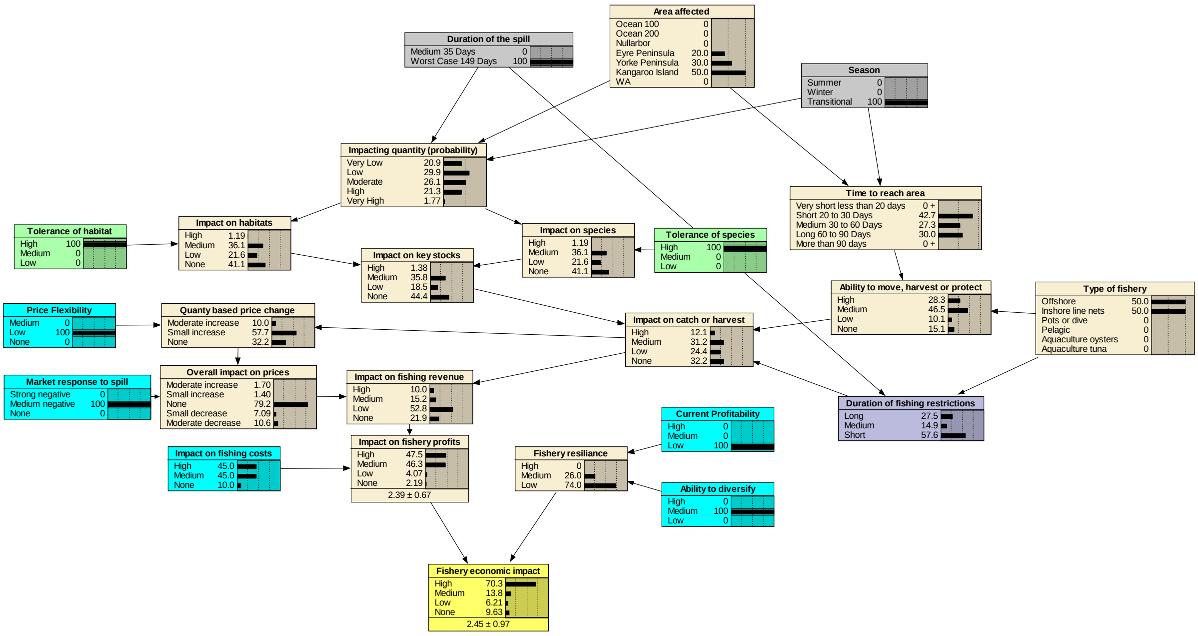
Large summer spill (149 days)



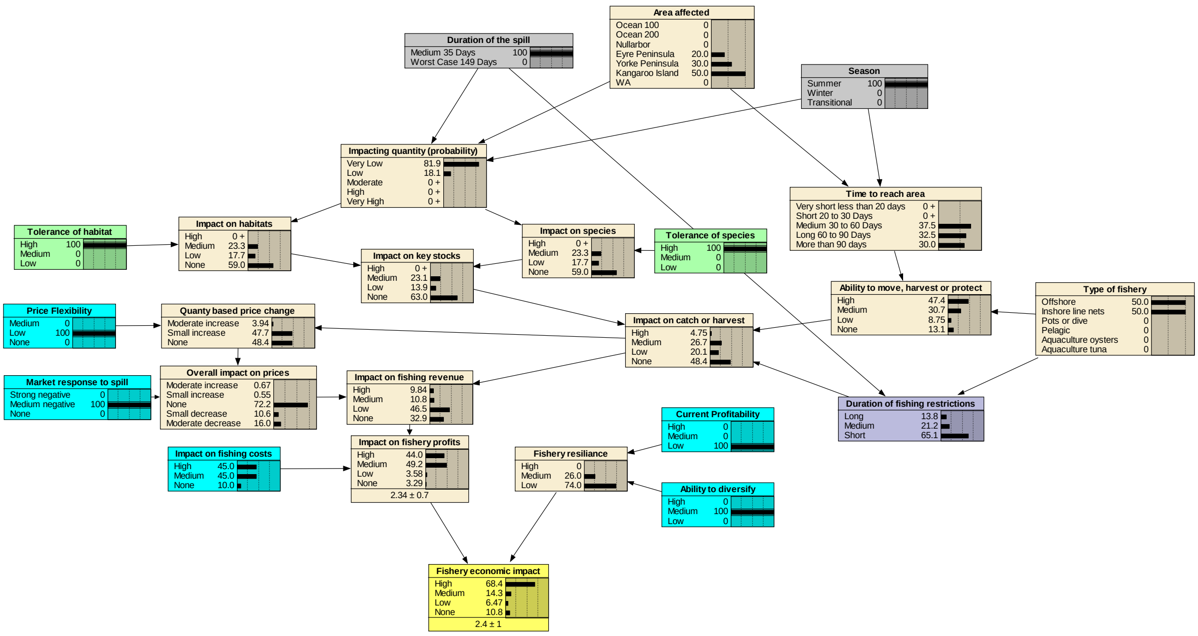
Large winter spill (149 days)



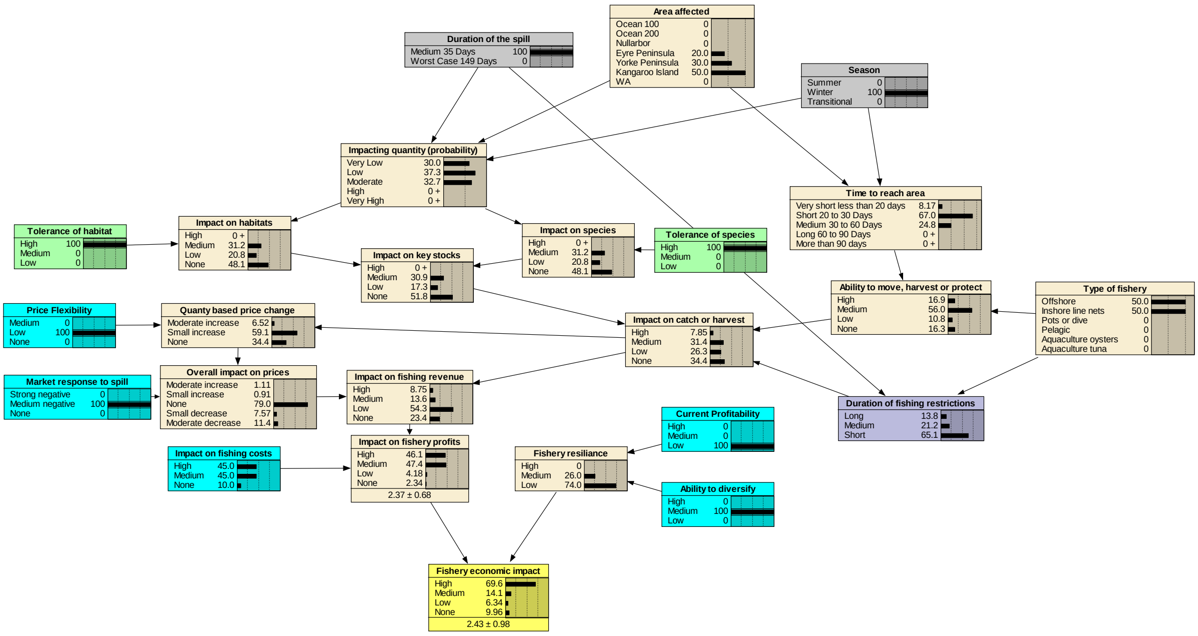
Large transitional season spill (149 days)



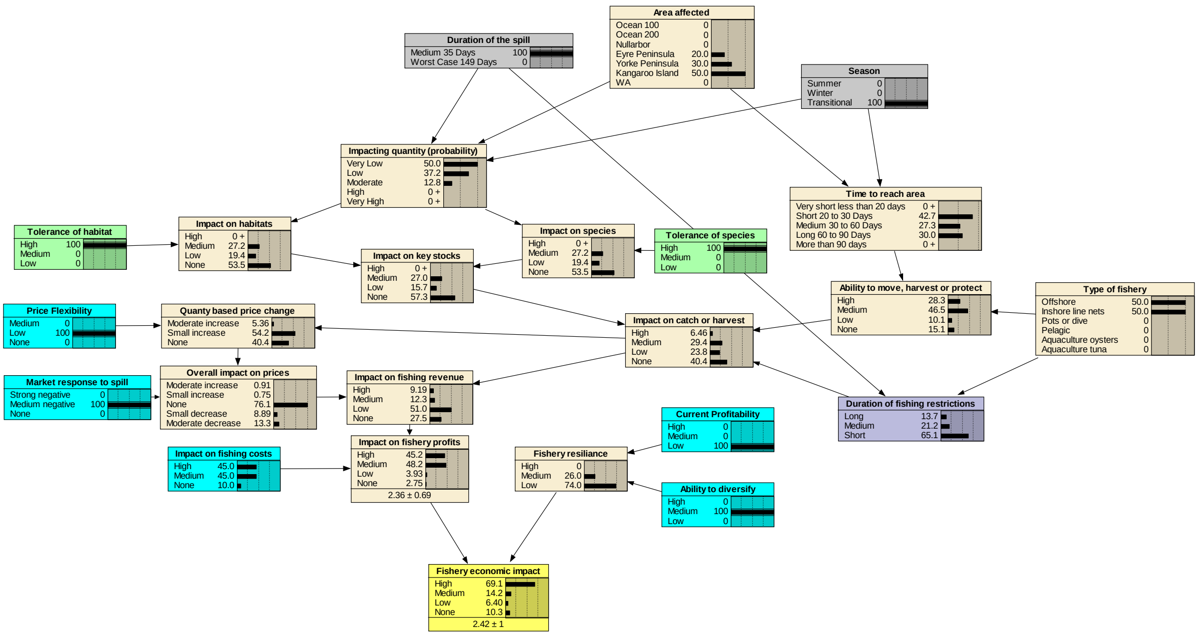
Medium summer spill (35 days)



Medium winter spill (35 days)



Medium transitional season spill (35 days)



Abalone (Western and central zone)

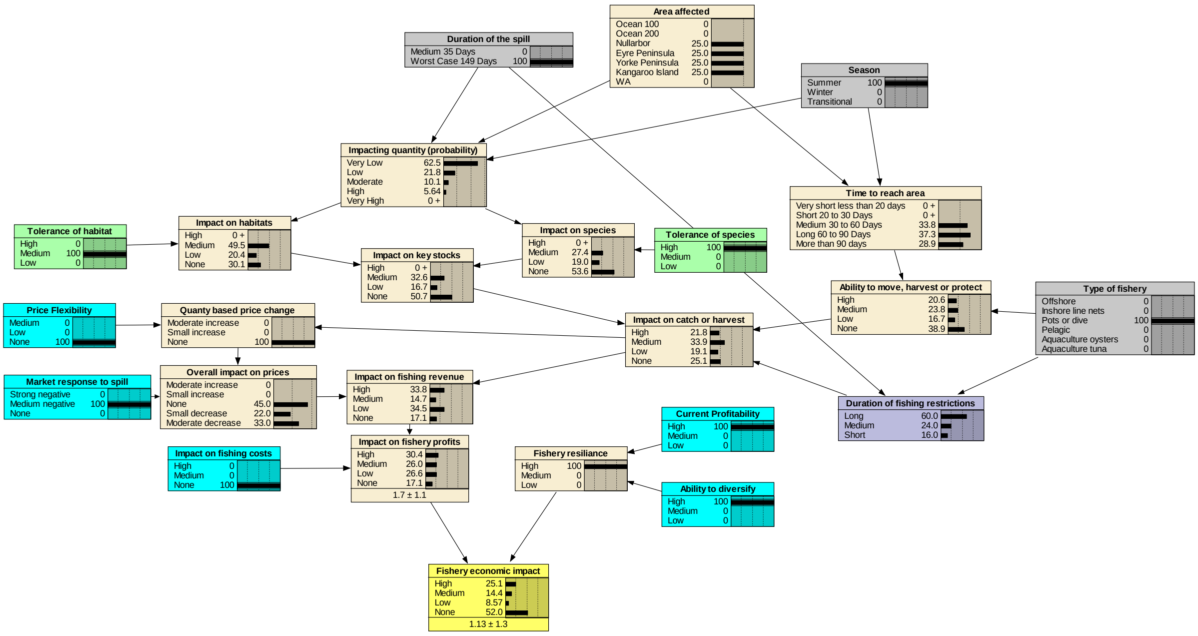
Assumptions: The evidence on the impact of an oil spill on abalone stocks is mixed. Some studies have found that fertilised embryos are sensitive to low concentrations of dispersants (Singer *et al.* 1991), while post-oil spill monitoring of reefs in Tasmania found abalone densities were the same in affected and unaffected areas, and also before and after in the heavily oiled region (Edgar and Barrett 2000). Other studies have found heavy mortality of abalone following an oil spill, with populations depressed for around two years (Nelson-Smith 1982). However, in the latter case much of the abalone was in shallow intertidal waters. Toxicity in molluscs has been estimated to be

between 5-50 ppm for soluble aromatics (1-100 for gastropods), although physical coating (such as in intertidal waters) may also result in mortality (Moore and Dwyer 1974)

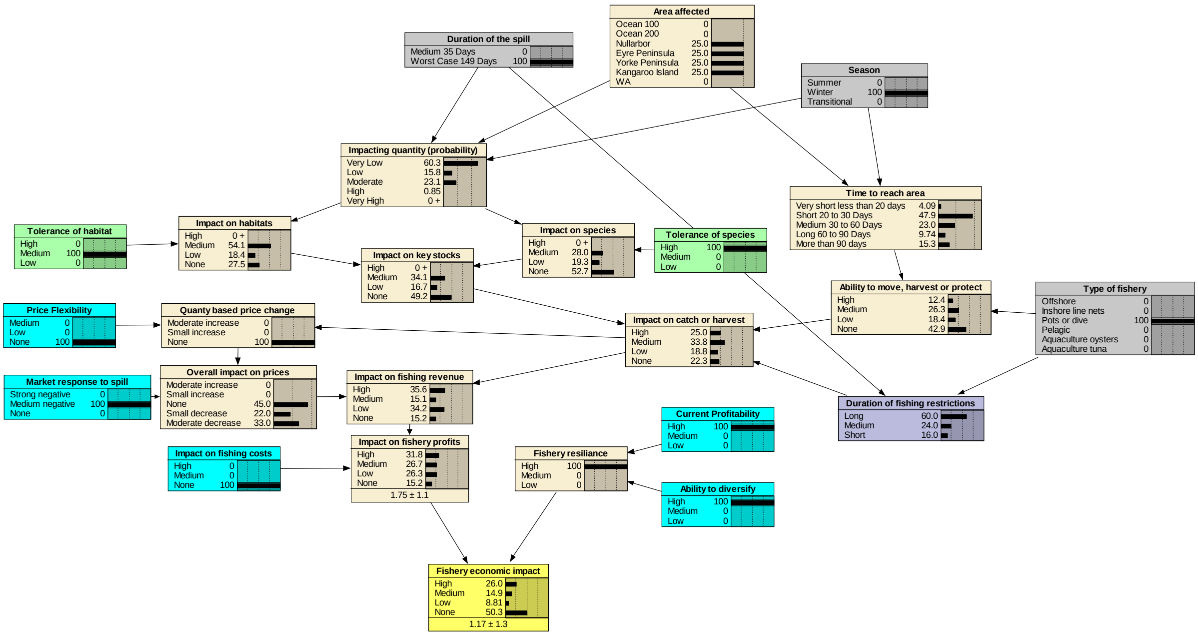
In the GAB, commercial fishing takes place in waters greater than 5 m deep (and less than 20 m) (PIRSA Fisheries & Aquaculture 2012). As a result, the likelihood of physical coating is small. However, oils settling in the water may negatively impact the abalone habitat. Hence, the assumption is that tolerance of the species is high, but tolerance of the habitat is medium.

Most of the abalone is exported, so the price flexibility is assumed zero. There may be some negative response from the export market which may affect prices, but as abalone is sent to these markets from a variety of Australian sources this will not be substantial (so assume medium). Profitability in the industry is high. Much of the quota is held by non-fishers, who are able to diversify their incomes and potentially "sit-out" the closure period (so resilience is likely to be high). There is little potential to relocate fishing activity in response to the spill, so cost changes are likely to be negligible.

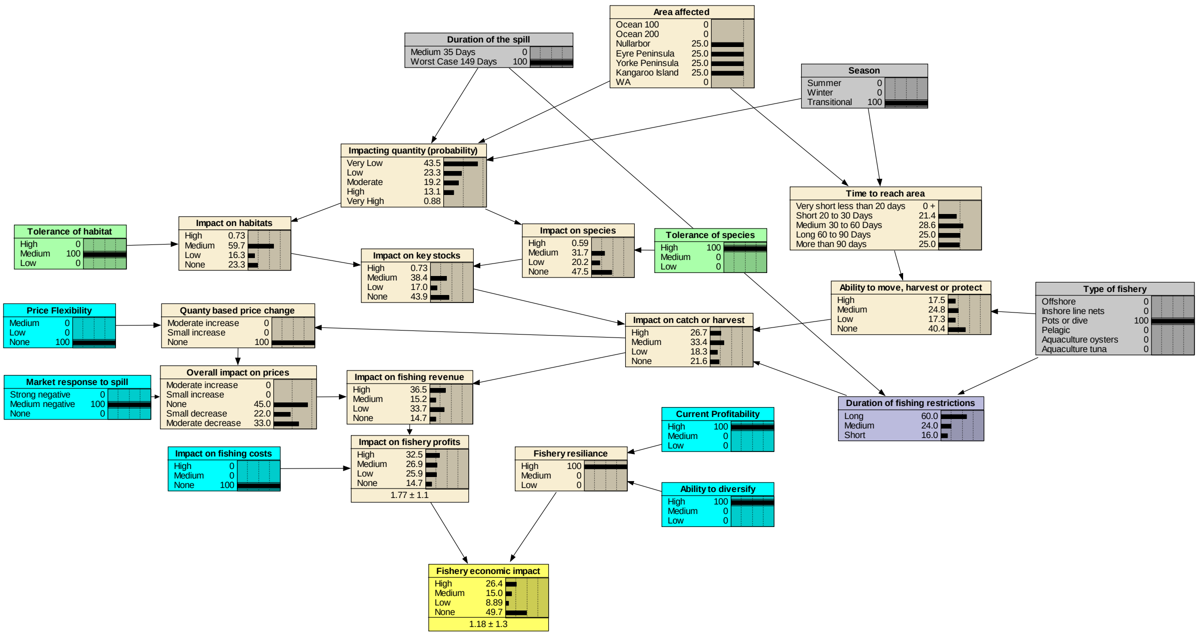
Large summer spill (149 days)



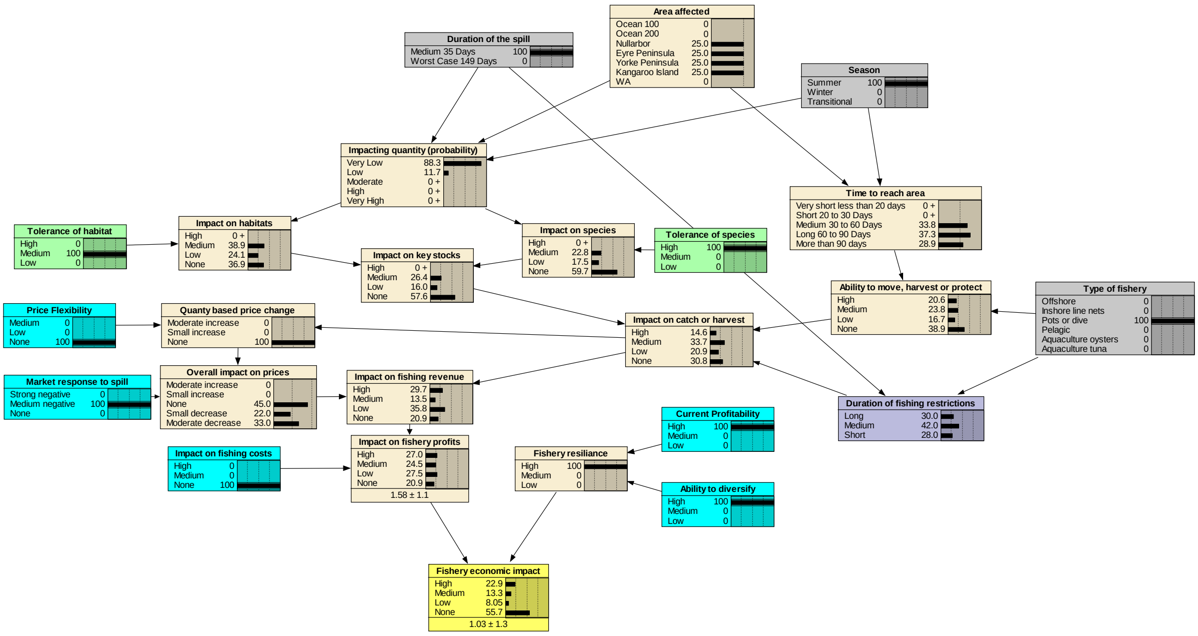
Large winter spill (149 days)



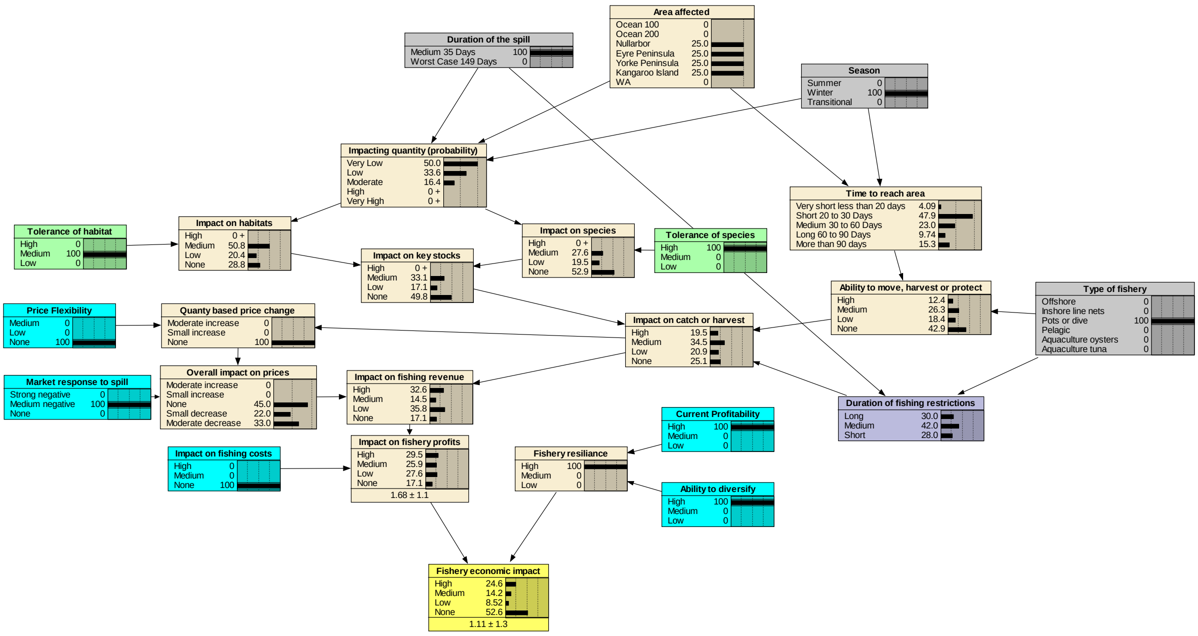
Large transitional season spill (149 days)



Medium summer spill (35 days)



Medium winter spill (35 days)



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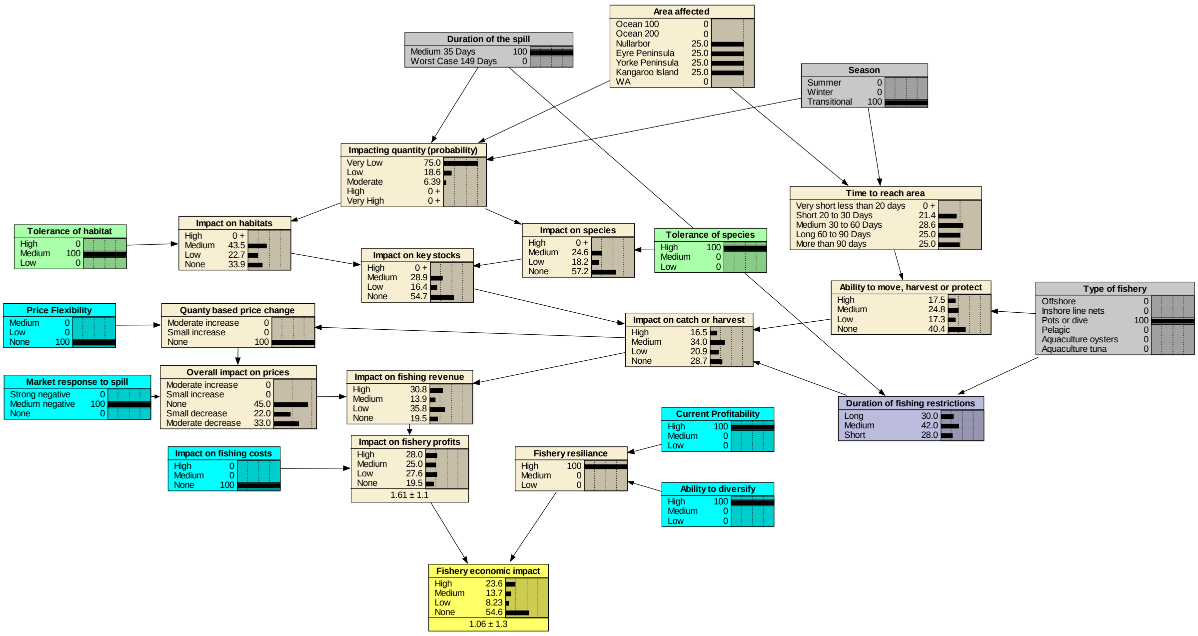


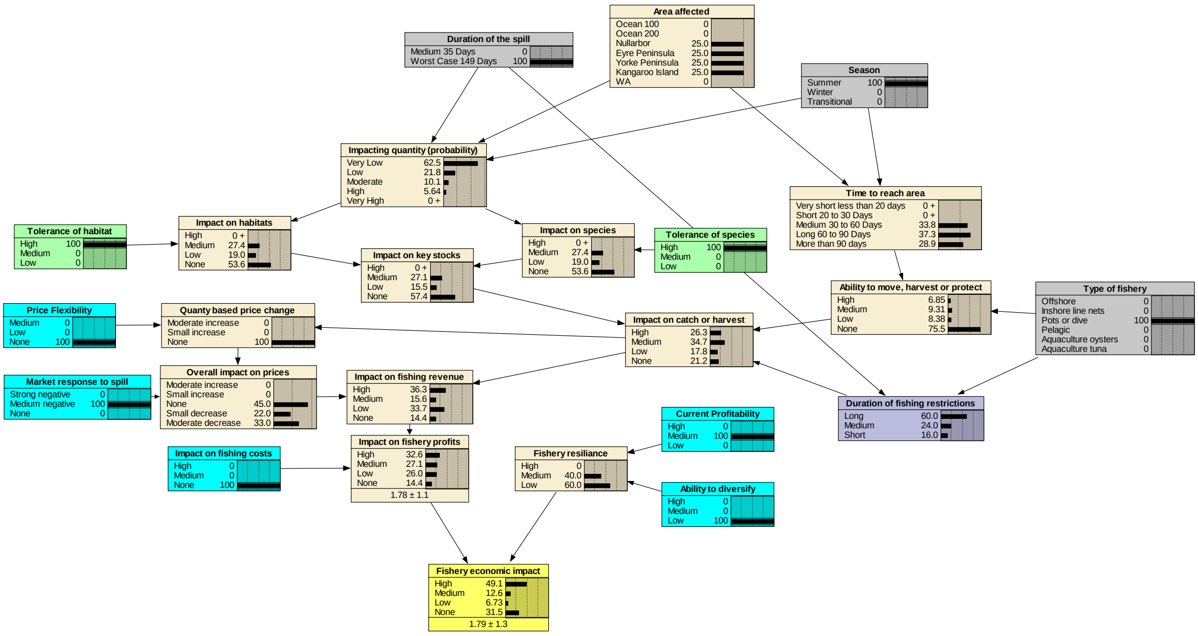
Lobster (Northern Zone)

Assumptions: Studies elsewhere suggest that the tolerance of lobster to oil spills is high. Toxicity in lobster has been estimated to be between 1-10 ppm (Moore and Dwyer 1974), Mortality of larvae is high if exposed to oil at hatching, but was found to be negligible if exposed to the contaminated water after day 2 from hatching (laboratory experiments) at concentrations of around 10ml/litre (Katz 1973). Other studies found oil lethal to larvae at 100ppm (0.1ml/litre), and affects moulting down to 0.01ml/l (1ppm) (Wells 1972). Empirical evidence of impacts of oils spills on lobster catch has been negligible (Seymour and Geyer 1992; Born *et al.* 2003). Laboratory tests have shown that marine organisms contaminated by various types of oils rapidly purge themselves once their exposure to such oils has been terminated. Preliminary studies on the effects of a crude oil on the four larval stages of the American lobster indicated that concentrations of 0.1 and 1.0 ppm crude oil did not diminish survival success of test organisms. The population levels, growth rate and fecundity of lobsters are not affected by low-level chronic exposure to oil (Mertens and Gould 1979).

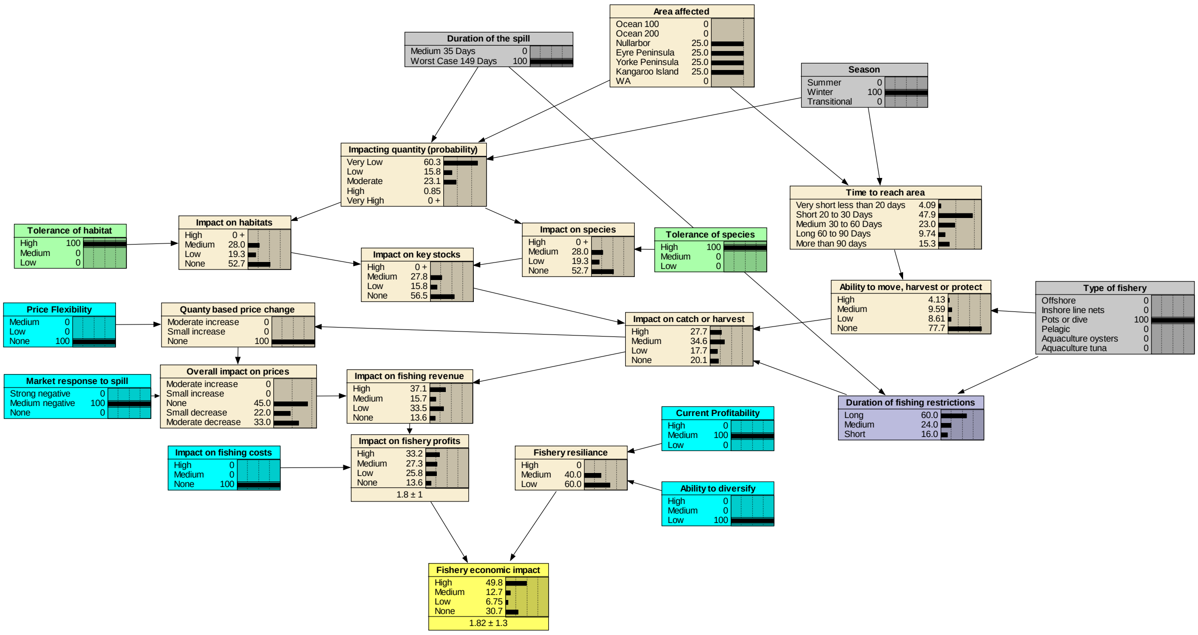
A high proportion of lobster are exported so prices are assumed to be inflexible. There is evidence that consumers respond to the physical characteristics of lobsters (Norman-López *et al.* 2011), so it is likely that there will be some negative response in the short term to lobster that is believed to have been contaminated.

The industry is reasonably profitable, but potential for diversification is low as the fishers are limited in where else (or how else) they can fish. As a result, there will be negligible cost changes.

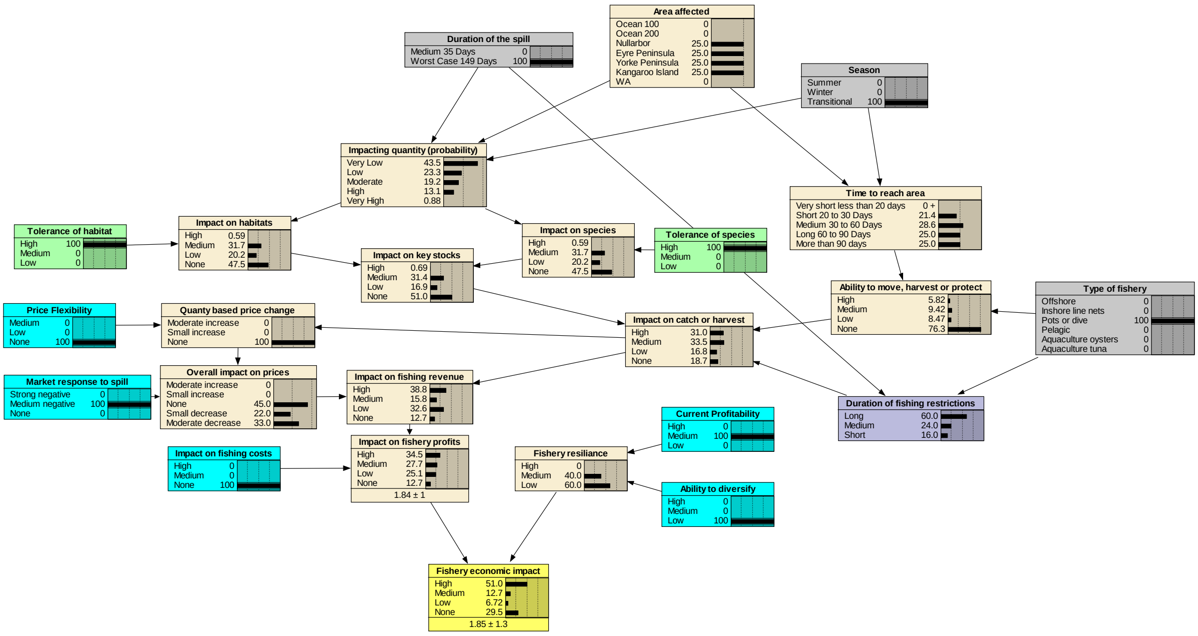
Large summer spill (149 days)



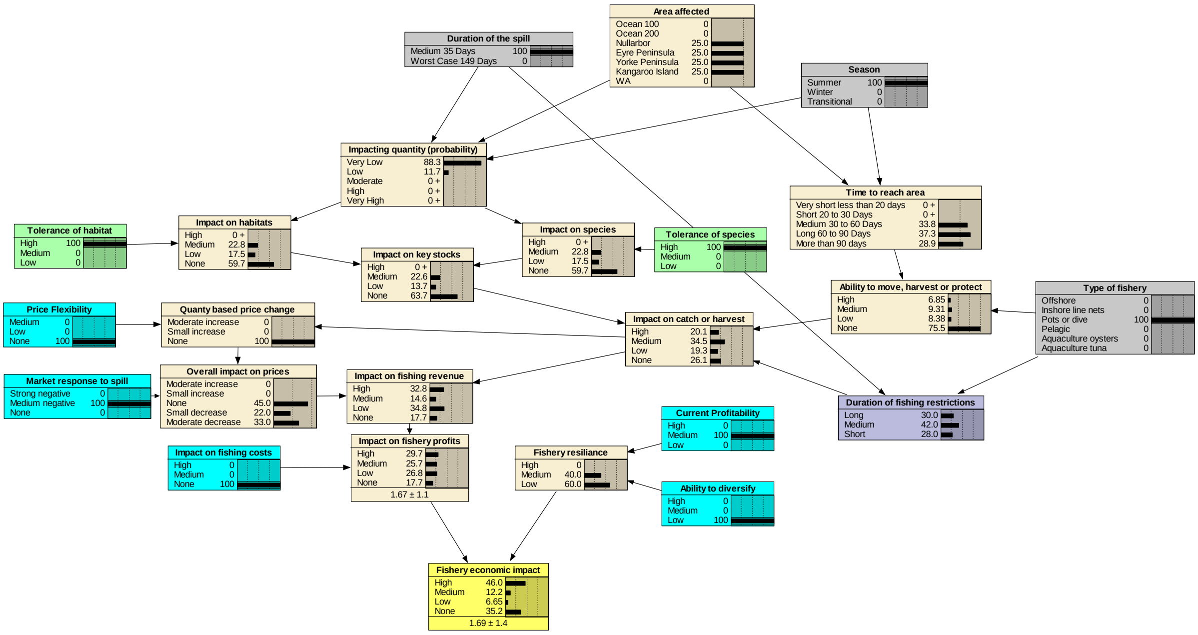
Large winter spill (149 days)



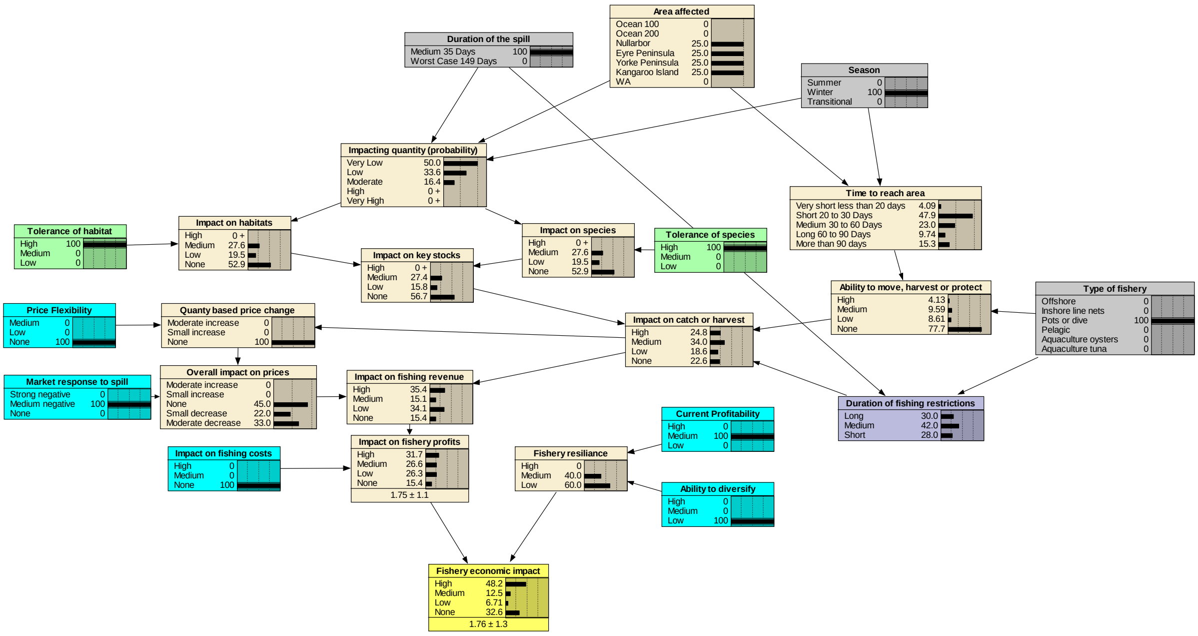
Large transitional season spill (149 days)



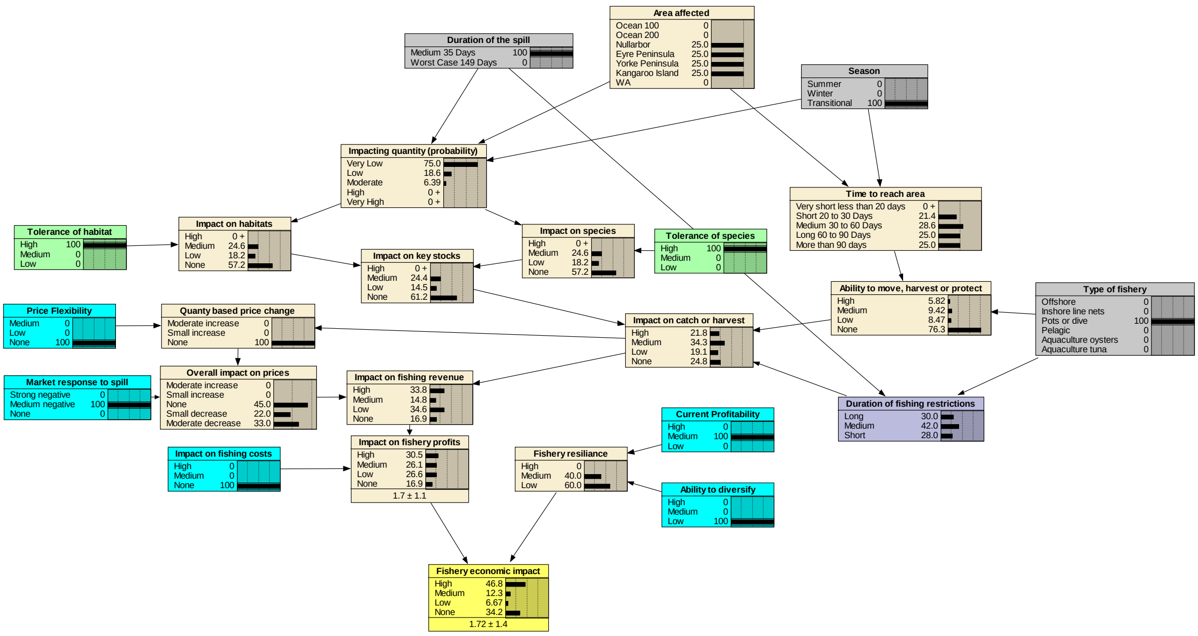
Medium summer spill (35 days)



Medium winter spill (35 days)



Medium transitional season spill (35 days)



Oyster farming

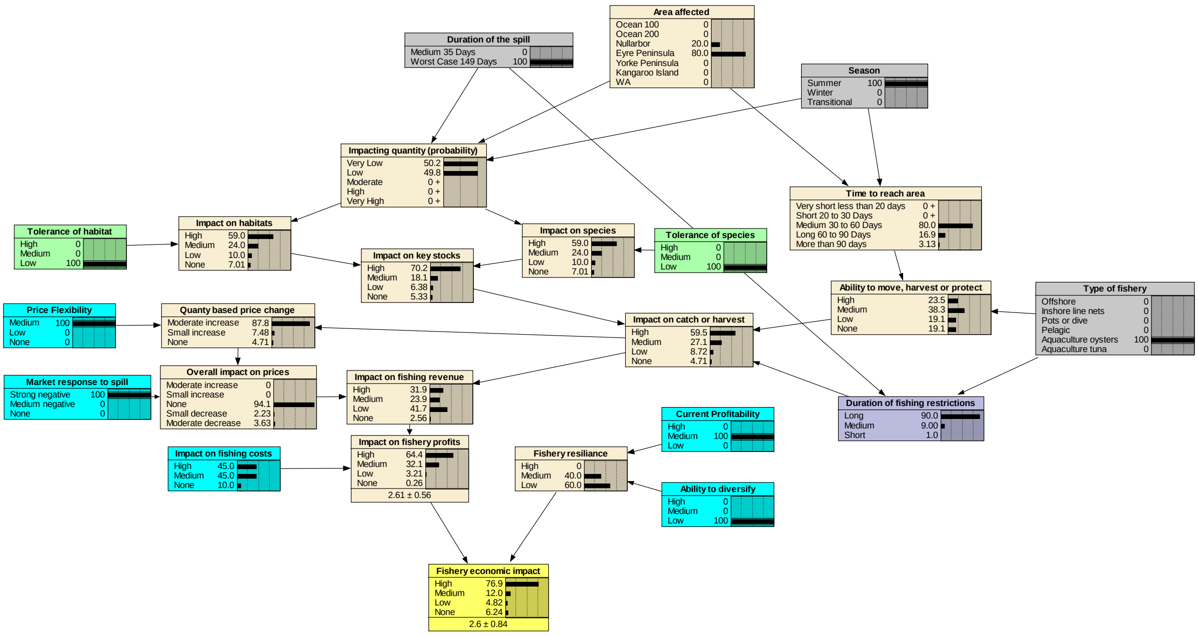
Assumptions: Most of the oyster farming occurs between Eyre Peninsula and Ceduna, so the area affected was assumed to be 20% Nullarbor and 80% Eyre Peninsula. Depending on the time taken for the oil to reach the area, producers may have the potential to implement some form of barrier that may reduce the impact of the oil on the species. Producers also have the potential to harvest at least some of their stock albeit at a smaller size and hence lower price. This is captured in the model through a higher cost, associated with the opportunity cost associated with selling smaller oysters.

The biophysical impact of oil on the oysters themselves is potentially less of an issue than the market impacts. Studies elsewhere have seen a substantial reduction in the oyster immune system more than 12 months after exposure to a spill (Donaghy *et al.* 2010). Other experimental studies have found low direct mortality as a result of oil exposure, but a rapid accumulation of hydrocarbons and a very slow release (Stegeman and Teal 1973). The oysters are expected to be largely unmarketable (due to perceived health risks) if exposed to the oil, and the habitat is also likely to be adversely affected (i.e. the growing platforms will need to be replaced). As a result, tolerance, in terms of impact on the harvestable stock, of both the species and habitats are expected to be low.

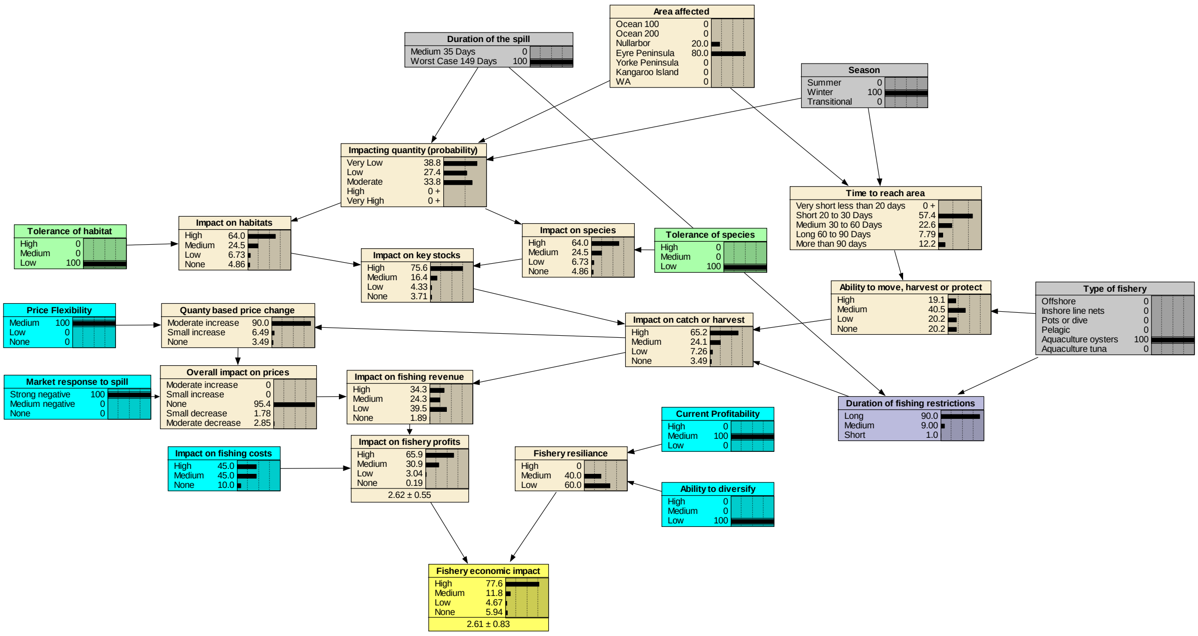
The market is expected to react mostly negatively over concerns of contamination (based on the experiences in the Gulf of Mexico), but this is potentially going to be offset to some extent by a medium own price flexibility (Schrobback *et al.* 2014).

The ability of the producers to diversity in the short term is low. Current profitability is not known, but assumed to be medium.

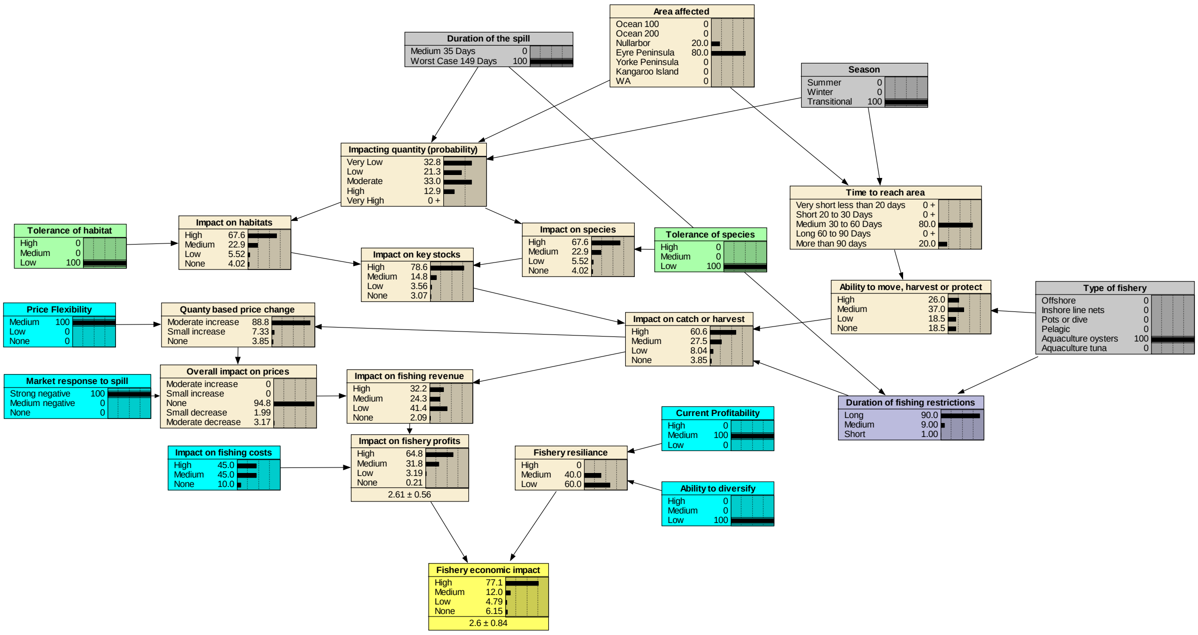
Large summer spill (149 days)



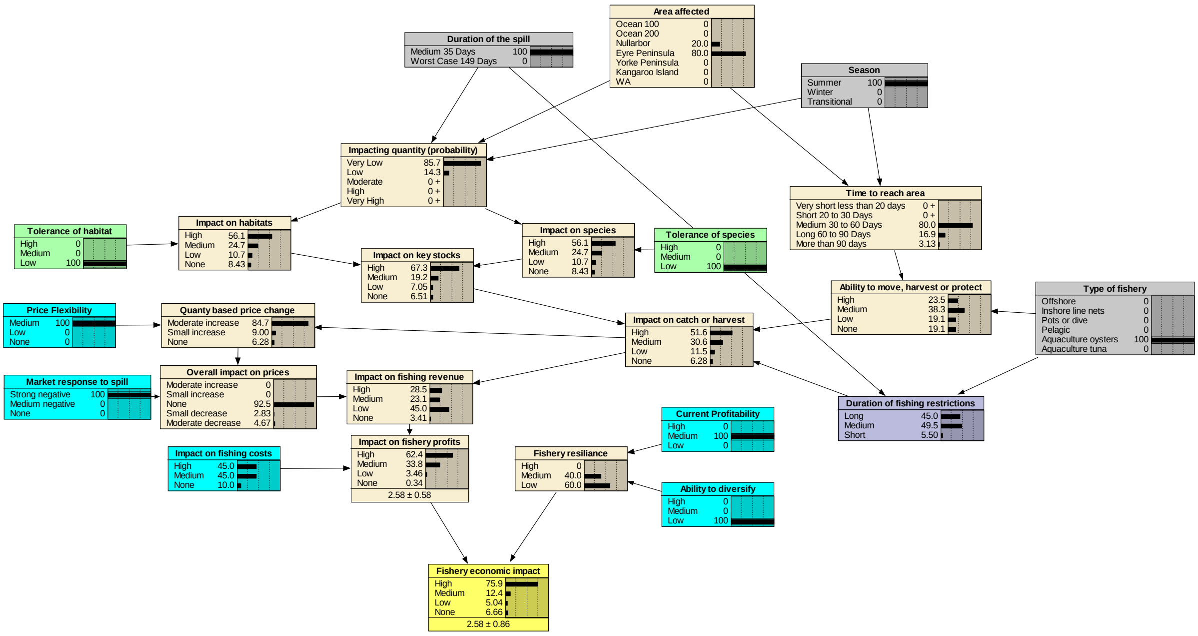
Large winter spill (149 days)



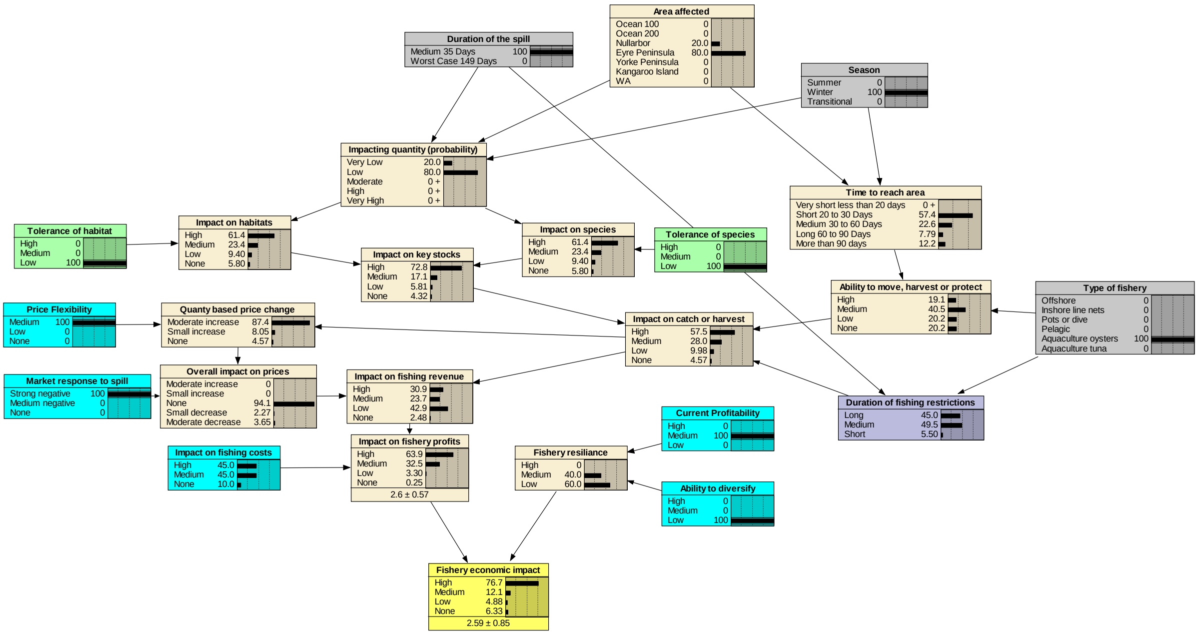
Large transitional season spill (149 days)



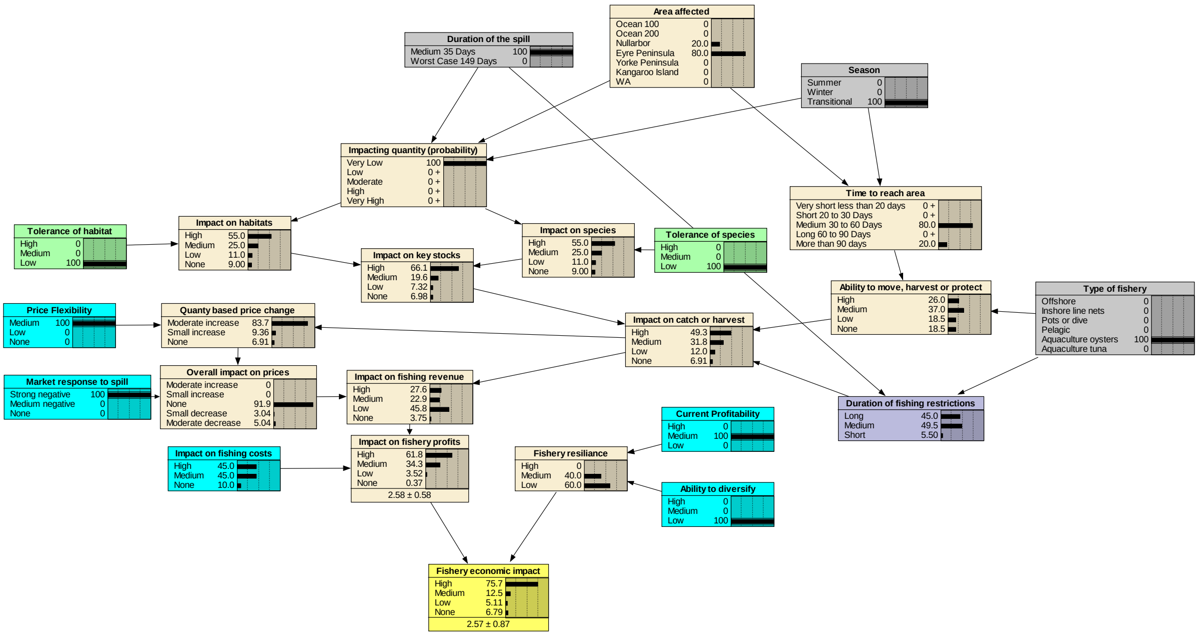
Medium summer spill (35 days)



Medium winter spill (35 days)



Medium transitional season spill (35 days)



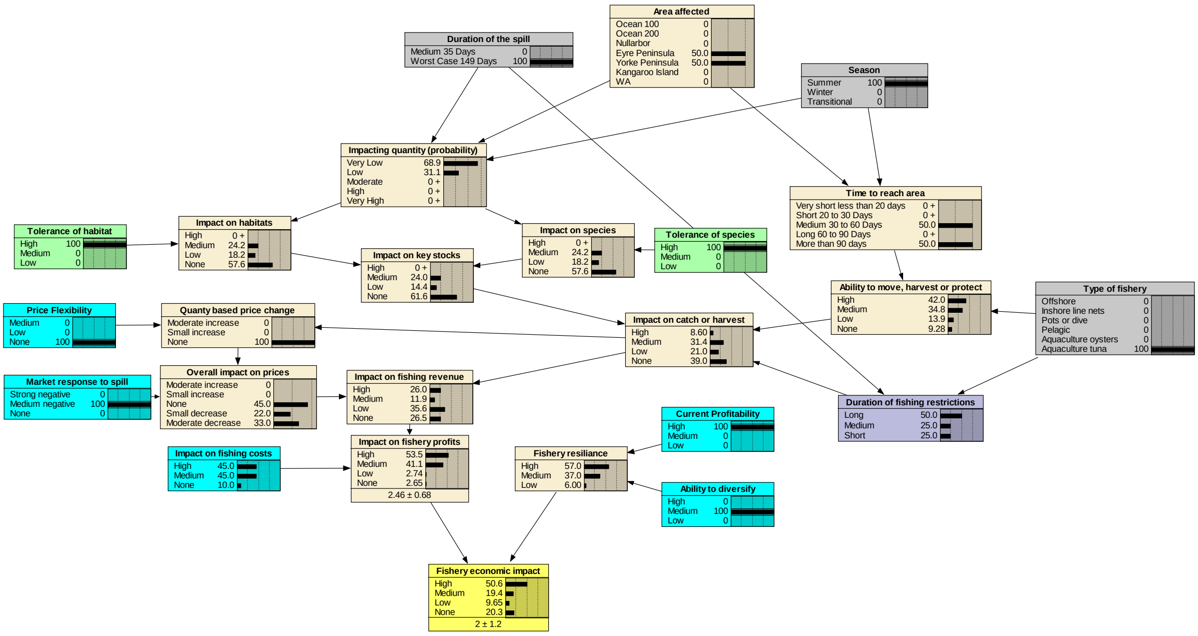
Southern Bluefin Tuna ranching

Assumptions. Farmers are able to move cages to less affected areas and/or provide barriers that reduce the impact of the oil on the caged fish. Tolerance of both the SBT and the habitat is assumed to be high.

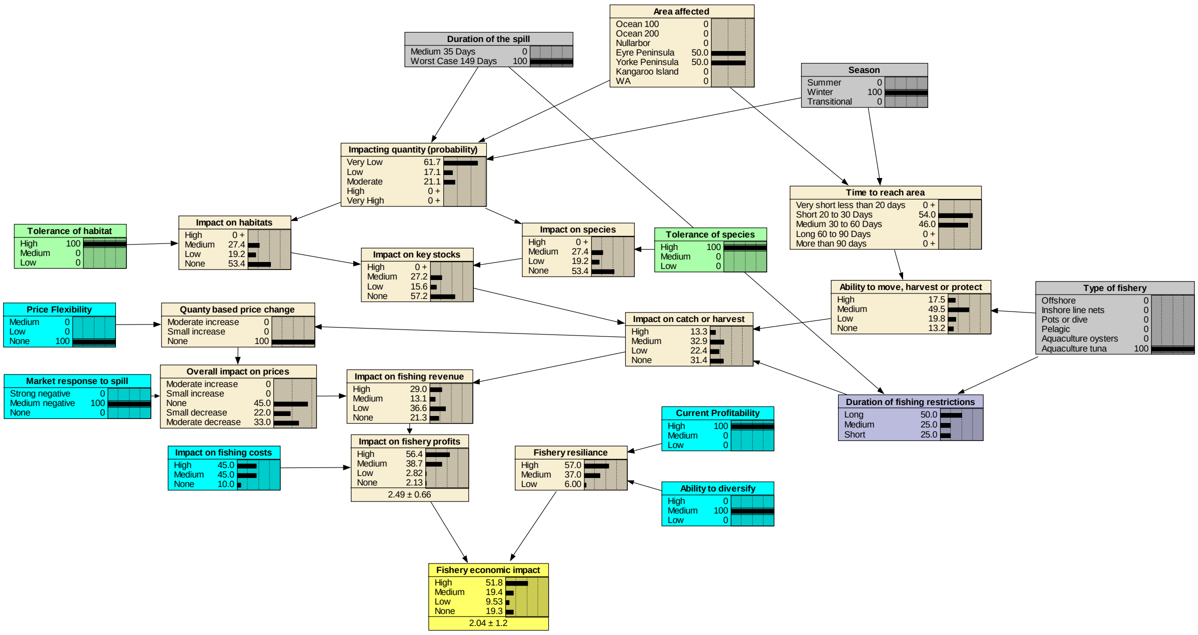
Market response is assumed to be medium negative as there may be reluctance for the export market to take potentially contaminated fish. For this reason the duration of the restriction is also likely to be reasonably long (endogenous in the BBN). As the export market is competitive, price flexibility is assumed to be zero.

The profitability of the industry is assumed to be high, with medium ability to diversity their product into other markets if the export market is less attractive.

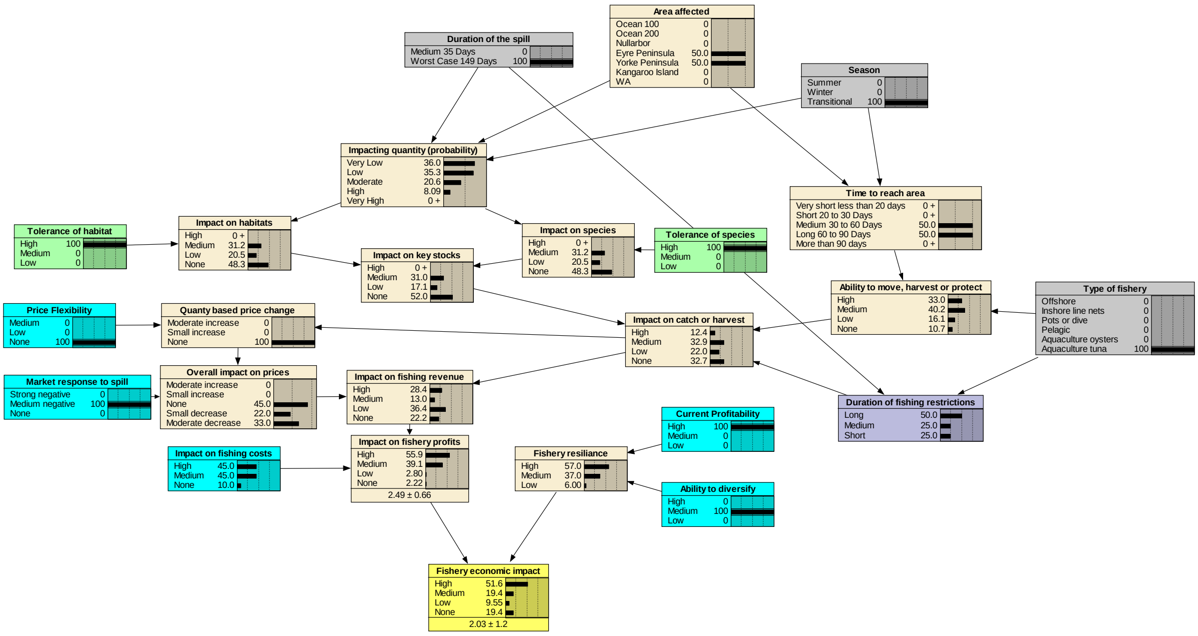
Large summer spill (149 days)



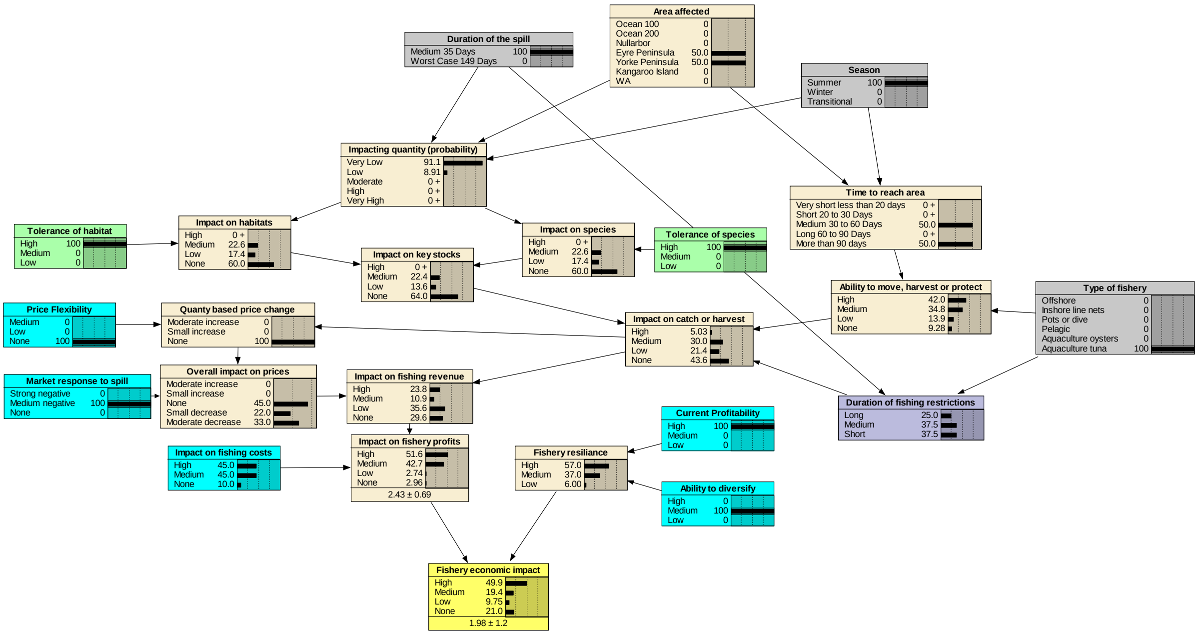
Large winter spill (149 days)



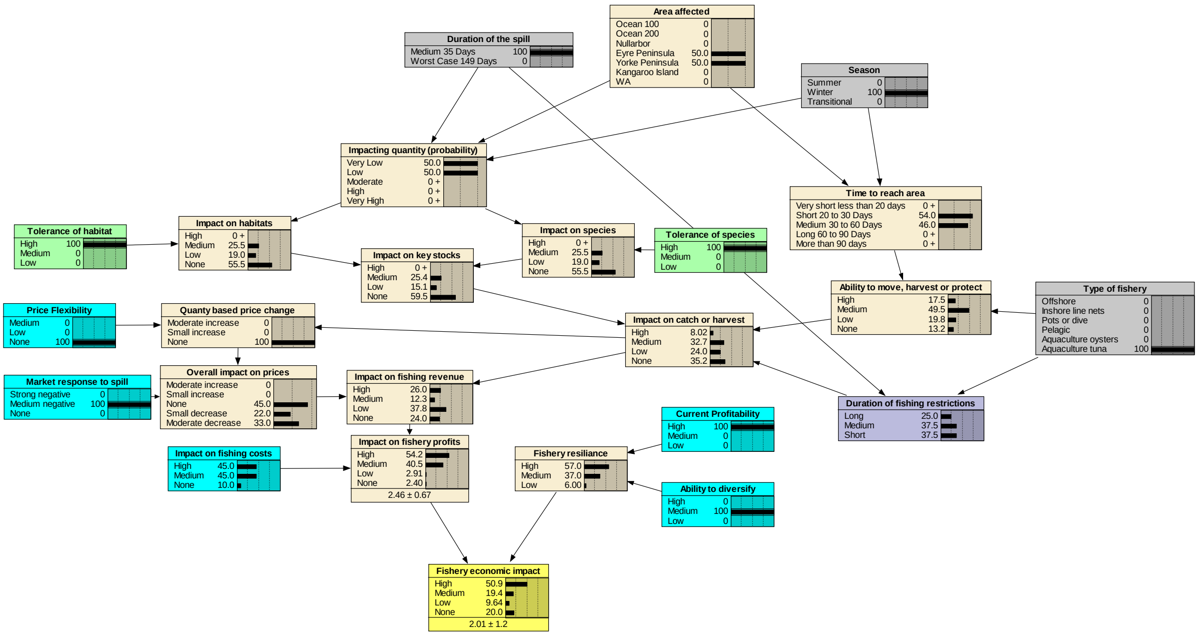
Large transitional season spill (149 days)



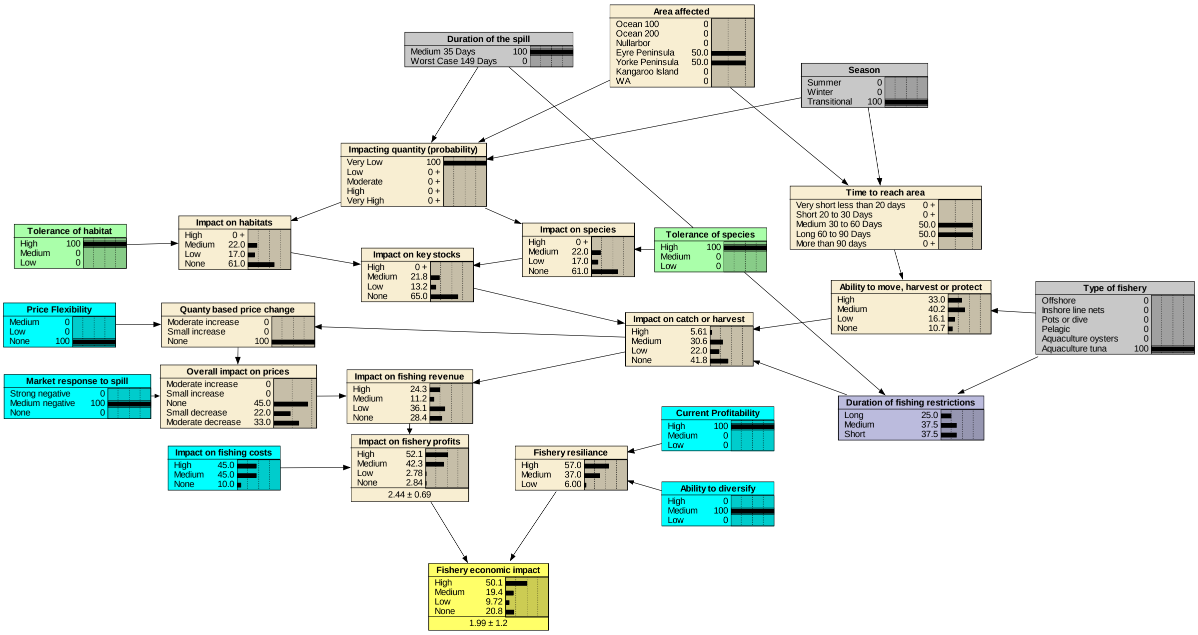
Medium summer spill (35 days)



Medium winter spill (35 days)



Medium transitional season spill (35 days)



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Aps, R., Herkül, K., Kotta, J., Kotta, I., Kopti, M., Leiger, R., Mander, Ü. and Suursaar, Ü. (2009b). Bayesian inference for oil spill related Net Environmental Benefit Analysis, *WIT Transactions on Ecology and the Environment* 126, 235-246.

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