PTTEP

Montara Environmental Monitoring Program

Report of Research


Green sea turtles were studied as part of the Montara Environmental Monitoring Program

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UNDERSTANDING BIODIVERSITY IN THE TIMOR SEA

Introduction

An important response by PTTEP Australasia to the 2009 Montara oil spill was to commission a new world class body of independent scientific research into the marine life and ecosystems of the Timor Sea.

In August 2012, we published our first report on the Montara Environmental Monitoring Program. Work on many of the studies has continued in the past year.

I am now proud to introduce you to this updated Report of Research, which features extensive discussions of each individual study, as well as an overarching discussion of the research in its entirety. I hope the report will help raise awareness of the biodiversity of the Timor Sea region and its environmental significance.

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Widespread public availability of the research will also directly inform and influence new projects and practices by the Australian oil and gas industry and by government. It will assist in assessing conservation and environmental values and risks and help ensure the most effective management procedures are identified and implemented.

The significant new body of baseline scientific data the monitoring program has created on the Timor Sea and the northern Australian coastline highlights the need for a more focused and coordinated regional approach to environmental data collection.

Coordinated environmental monitoring will help ensure the region is protected for future generations. Applying consistent methods has the potential to improve the utility of collected data, ensure its wider use and make it more transferable.

PTTEP AA is looking at providing a leadership role in the Timor Sea region of operations through ongoing involvement in, and the resourcing of, scientific research.

PTTEP has always accepted full responsibility for the Montara wellhead blowout and subsequent uncontrolled flow of hydrocarbons into the Timor Sea. We paid the full cost of the clean up operations.

PTTEP AA's management culture, operational capabilities, safety processes and environmental systems have been transformed since 2009. This has been carried out under the Montara Action Plan which the company developed in close consultation with the Australian Government to address the root causes of the incident, as identified in the 2010 Borthwick Commission of Inquiry.

Sharing the lessons learnt from Montara with industry and governments is an important part of improving the industry's safety and operational performance. Sharing the environmental knowledge we have gained through the incident is also vital to protecting our valuable marine and coastal habitats for the future.

On behalf of PTTEP, I am pleased to share this wealth of environmental research with industry, the scientific community and the broader public so that it will continue to contribute positively to our collective knowledge of the Timor Sea marine environment.

Ken Fitzpatrick
Chief Executive Officer
PTTEP Australasia

A NEW BODY OF WORLD CLASS RESEARCH ON THE TIMOR SEA

Montara Environmental Monitoring Program

The environmental monitoring program triggered by the 2009 Montara oil spill in the Timor Sea is one of the most extensive of its type ever undertaken in Australia. The series of independent studies by leading scientific research institutions commenced soon after the incident in August 2009 and mostly concluded by mid-2013.

In October 2009, PTTEP Australasia (PTTEP AA) reached agreement with the Australian Government for the company to fund the monitoring program to determine any impacts on the environment.

The program was developed by PTTEP AA in close consultation with the office of the Federal Minister for the Environment and the Department of Sustainability, Environment, Water, Population and Communities (SEWPaC). SEWPaC, in turn, sought independent expert advice on the establishment of the environmental monitoring program from organisations such as the Australian Institute of Marine Science and Monash University, as well as relevant state and territory agencies.

The Montara Environmental Monitoring Program has created a significant body of knowledge which is helping cultivate a greater understanding of biodiversity in the Timor Sea. This will reduce uncertainty in identifying industry impacts and contribute to better planning and project design.

Findings from the research will also assist both industry and government in assessing conservation and environmental values and risks; and in ensuring and identifying the most effective management approaches for the region.

Data collected across larger regional areas, over longer periods of time and using consistent methods, will enable increased knowledge relating to key aspects of the environment:

- simply knowing what is 'there' will provide a census of information about the diversity, distribution and population numbers of species and communities
- it will allow the identification of higher risk/higher sensitivity habitats, endangered and other species and biodiversity
- over time, it will provide data on the variability of the environment and how it changes over time in response to events such as climate change and coral bleaching
- it will provide information on how natural resources are affected by other human stresses such as fishing, shipping and coastal runoff
- integrated research will provide more information on the complex ecological processes which exist, including primary production, reproduction, and population dynamics which may not be currently well understood.

This increased knowledge will enable more certainty in assessing and predicting impacts from industry, enabling better planning of activities and the implementation of mitigation measures.

The research has contributed knowledge to the variability of the environment, how it changes over time and how natural resources are affected by human stresses.

The data compiled as part of the environmental monitoring program is available publicly on the SEWPaC website – www.environment.gov.au/coasts/oilspill/scientific-monitoring.html – and is being shared widely through industry presentations and the media.

Montara environmental studies sampling locations

The map illustrates the locations of field work for the scientific studies undertaken by indepdendent research agencies as part of the PTTEP AA-SEWPaC environmental monitoring program

Scientific studies

A list of the Montara environmental monitoring studies commissioned, developed in consultation with SEWPaC, is outlined in the table below.

To view the full scientific studies visit: *www.environment.gov.au/coasts/oilspill/scientific-monitoring.html*

	Scientific Study	Research organisation
1.	**S2 –** Shoreline ecological assessment aerial surveys (baseline only)	James Cook University Australia; TropWATER
2.	**S3 –** Assessment of fish for presence of oil	Department of Fisheries
3.	**S3A –** Olfactory analysis of Timor Sea fish fillets	Curtin University Department of Environment and Agriculture
4.	**S4A –** Assessment of effects on Timor Sea fish	Curtin University Department of Environment and Agriculture
5.	**S5 –** Offshore banks assessment survey	Australian Institute of Marine Science
6.	**S6.1 –** Shoreline ecological ground surveys (corals)	Australian Institute of Marine Science
7.	**S6.2 –** Shoreline ecological ground surveys (turtles and sea snakes)	Charles Darwin University Faculty of Engineering, Health Science and the Environment School of Environment
8.	**S6.3 –** Shoreline ecological ground surveys (seabirds and shorebirds)	Monash University Australian Centre for Biodiversity, School of Biological Science
9.	**S7.1 –** Oil fate and effects assessment – trajectory analysis	Asia-Pacific asa
10.	**S7.2 –** Oil fate and effects assessment – dispersant oil modelling	Asia-Pacific asa

THE MONTARA OIL SPILL

An overview

The Montara incident occurred on 21 August 2009, when there was a sudden ingress of gas into the wellbore of the Montara H1 development well, rising to the surface. This resulted in an uncontrolled flow of hydrocarbons into the Timor Sea which lasted for 74 days. The well was brought under control and the flow ceased on 3 November 2009.

The Montara incident is estimated to have spilt approximately 400 barrels per day of light sweet crude oil into the marine environment, or an estimated 30,000 barrels in total during the 74 day incident. Montara oil is light orange / brown in colour – unlike the thick black crude oil often associated with oil spills.

Trajectory modelling and real time observations confirmed the main area affected on by the spill was within a 23 kilometre radius of the well head. The slick beyond this area was predominantly a lighter waxy film and surface coverage was significantly less.

The largest single area affected on during the incident at any one time was 11,183 square kilometres. Sixty two per cent of the total surface area was affected for two hours or less. No hydrocarbons were detected in the marine environment after 94 days.

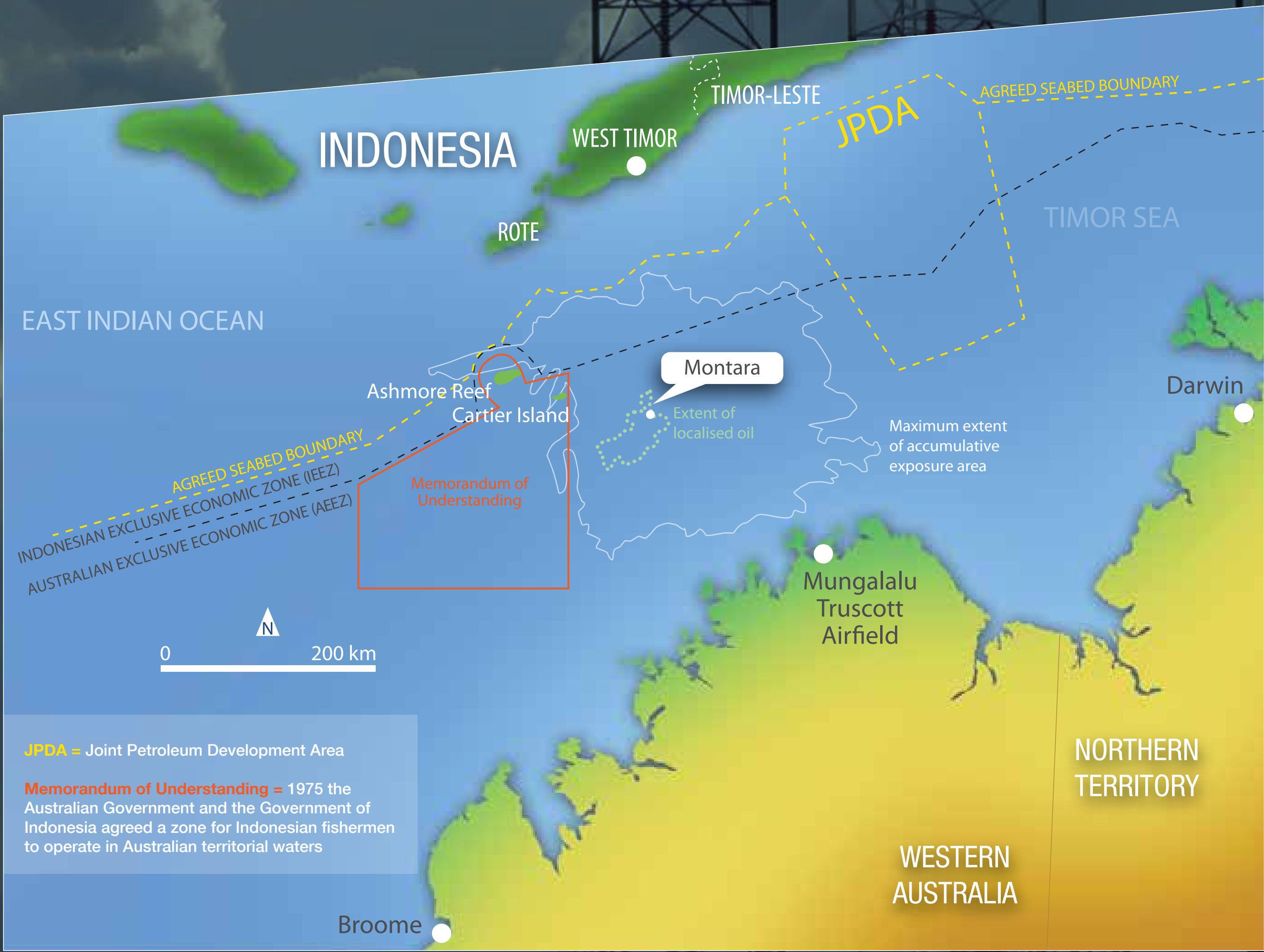
During the incident response, more than 130 surveillance flights were undertaken by the Australian Maritime Safety Authority (AMSA), the government agency which manages Australia's oil spill response. Regular satellite imagery and trajectory modelling was also assessed. The combined data accurately mapped daily slick positions and played an important role in directing vessel-based containment and recovery operations.

Observations during the incident confirmed the oil weathered quickly to form solid wax residues within seven to ten days of its release. The most toxic elements of the hydrocarbons were discharged to the atmosphere on release, or within the first two hours of the incident. Scientific studies suggest the spill size, and the damage it caused, ranks low in comparison to other marine oil spills in Australia and internationally.

No oil reached the Australian mainland or Indonesian coast – the closest recorded from Australia was 35 kilometres; the closest recorded from Indonesia was 94 kilometres. Some patches of oil drifted into deep waters off the Timor Trench, where fast moving currents associated with the Indonesian Throughflow current carried weathered oil patches in a south westerly direction away from the Indonesian coastline. (For more detail on the distribution of oil and the use of Australian Government-approved dispersants as part of the AMSA-directed response, see the Oil fate and effects assessment (trajectory analysis) discussion in this report).

Both the 2010 Borthwick Commission of Inquiry and the Australian Maritime Safety Authority commended PTTEP AA for its response efforts. AMSA affirmed PTTEP AA provided excellent support through the provision of on-water response resources, financial support and monitoring programs.

The West Triton drilling rig at Montara, 2009


INDONESIA
WEST TIMOR
TIMOR-LESTE
ROTE
JPDA
AGREED SEABED BOUNDARY
TIMOR SEA
EAST INDIAN OCEAN
Ashmore Reef
Cartier Island
Montara
Extent of localised oil
Maximum extent of accumulative exposure area
Darwin
AGREED SEABED BOUNDARY
INDONESIAN EXCLUSIVE ECONOMIC ZONE (IEEZ)
AUSTRALIAN EXCLUSIVE ECONOMIC ZONE (AEEZ)
Memorandum of Understanding
N
0
200 km
Mungalalu Truscott Airfield
NORTHERN TERRITORY
WESTERN AUSTRALIA
Broome
JPDA = Joint Petroleum Development Area
Memorandum of Understanding = 1975 the Australian Government and the Government of Indonesia agreed a zone for Indonesian fishermen to operate in Australian territorial waters

A VOYAGE OF DISCOVERY

By Asa Wahlquist

Just four years after the Montara oil spill, which occurred late in 2009, scientists have compiled the most detailed description ever of the wildlife, fish and habitats of the Timor Sea. At the time, no one would have imagined this little-known area would become far better understood as a consequence of the spill. Dozens of scientists and researchers have produced a scientifically rigorous set of findings on turtles, sea snakes and commercial fish species; on bird populations; on corals and mangroves; and on the north west Australian coastline and an array of the Timor Sea's tiny islands, shoals and cays.

These findings are now providing scientists, industry and regulators with a benchmark against which to measure potential future events – natural occurrences such as cyclones, climate change, as well as those instigated by mankind – and better manage the valuable economic, environmental and social resources of the region.

As part of its response to the oil spill, PTTEP AA collaborated with a range of Australian authorities and organisations, quickly commissioning a unique cross-institutional team of scientists to build the most accurate and detailed account possible of the fate, impact and influence of the spilled oil.

In the months and years which followed, an extraordinary series of scientific studies and investigations took place. This remote region was little studied prior to the spill.

The research included a number of firsts and discoveries:

- the first study of seabirds and shorebirds on Cartier and Browse Island
- the first extensive monitoring of seabirds in north west Australia
- the first description of the benthic communities on Vulcan and Barracouta Shoals
- the most thorough survey of sea snakes and marine turtles ever undertaken in the region
- identifying that the mangroves and tidal wetlands were more extensive than anticipated on the massive length of the north west Australian shoreline surveyed
- concluding there are twice as many estuaries on this north west Australian shoreline than were previously known.

There was even the first reported case of hermaphroditism in goldband snapper.

New baseline information has been established for seabirds and shorebirds in the region; for terrestrial habitat on the islands of the Timor Sea; and for the commercially important fish species, red emperor, goldband snapper, saddletail snapper, Spanish mackerel and yellowspotted rockcod.

The result is the most comprehensive database ever generated of fish and birds, of sea snakes and marine turtles, of shoreline and intertidal habitats and their conditions, for this region.

Characteristics, movements and impact of the Montara oil

Montara is remote, located 260 kilometres from the north west Australian coast. The nearest land to Montara is Cartier Island, a two hectare single sand cay devoid of vegetation, 106 kilometres to the west. The more substantial 24 hectare Ashmore Reef lies 167 kilometres to the north west of Montara. The nearest seabed feature is the submerged Vulcan Shoal, 30 kilometres away.

The oil spill began on 21 August, 2009 and continued until 3 November. No oil from Montara was detected after 15 November 2009.

Most of the toxic elements from the oil spill were in a gaseous form and released into the atmosphere. The Australian Marine Safety Authority (AMSA) found the spilt surface oil did not contain any traces of the volatile hydrocarbons which would typically exist in this crude oil.

Oil can either weather to a persistent waxy substance, or it can oxidise, be degraded by microorganisms, or fall to the bottom in sediments.

"…no consistent adverse effects on fish health or their reproductive activity were detected…"

Timor Sea fish were the subject of a number of research studies

Most of the freshly spilled oil remained within 23 kilometres of Montara. The oil which occurred outside the containment area was mostly evident as sheens or waxy films. Sheens are typically less than 10 microns or 0.01mm thick, about one seventh the thickness of a human hair. Although it could be regarded as visual pollution, a sheen is 100 times lower than the level at which it would be rated as being of environmental concern.

Oil slicks are moved by tides, currents and winds. The Montara oil slick was monitored by daily fly-over observations by AMSA, recorded on both video and still camera. These images were matched with satellite observations. Modelling was produced using forecast ocean and meteorological (metocean) data.

The integration of this data with actual wind and ocean information resulted in hourly maps of the extent and state of the oil slick and ensured an incredibly detailed understanding of the movement and fate of the spilt oil. Only a negligible amount would be detected in the studies which followed.

Between three and nine per cent of the oil, measured in occurrences of visible oil, passed over the nearest topographical feature, Vulcan Shoal. There was one confirmed oil stranding of highly weathered oil surrounded by wax sheets on Ashmore Reef, the nearest exposed land.

Previous studies have also shown there is a background presence of petroleum hydrocarbons in the Timor Sea. They could originate from the oil industry, passing ships, discharge from fishing boats and from naturally occurring oil seeps.

In the wake of the spill, no oil was detected along the surveyed shoreline from Darwin to Broome. There were no obvious signs of disturbance at Vulcan Shoal. Although scientists found widespread traces of degraded oil at some sites, they reported the levels of hydrocarbons in the sediment were very low "and several orders of magnitude lower than levels at which biological effects become possible".

The first survey of Ashmore Reef and Cartier Island in April 2010 found no evidence of recent major disturbances at either location.

The spill occurred in a commercially important area for fishing. Associate Professor Marthe Monique Gagnon and Dr Christopher Rawson, from Curtin University, found evidence that fish had been exposed to petroleum hydrocarbons. They concluded, however, "no consistent adverse effects on fish health or their reproductive activity were detected".

Two years after the spill, they found there was a negligible ongoing environmental impact from the spill. They also found no olfactory evidence of oil taint in red emperor and goldband snapper fillets.

A team from the Western Australian Department of Fisheries studied the impact on four commercial species. They concluded the fish species from their two sampling trips "would probably have been safe to eat".

A team from Charles Darwin University found no evidence – in its March 2012 and March 2013 surveys – the spill had a long-term impact on sea snakes and marine turtles in the six reefs of the region.

The Federal Government Department of the Environment, Water, Heritage and the Arts (now SEWPaC) reported a small number (circa 50) of birds – common noddies, brown boobies and sooty terns – were affected by the oil spill. There were two confirmed reports of oil-affected sea snakes and one green turtle collected in the immediate vicinity of the oil spill. There were no confirmed reports of oil-affected whales or other cetaceans and no other confirmed reports of affected wildlife, despite extensive aerial and water-based patrols in the area.

Coastal habitats of north west Australia

Dr Norm Duke, from the University of Queensland, led a team which conducted old-fashioned exploration with the latest technology. His team's primary objective was to determine whether any of the waters, sediments, fauna or flora of the north west Australian coastline had been exposed to oil from the Montara spill. None was detected.

The survey began in Darwin on 9 November, 2009 and ended nine days and 5,102 kilometres of shoreline later at Broome. Using a helicopter, supported by a vessel, the team flew the length of the coastline at a height of 500 metres. They recorded images of the entire area on high definition video cameras and digital still cameras, all of which were synchronised in time and with GPS units.

5,102 kilometres of north west Australian shoreline was surveyed as part of the research program

They conducted on-ground surveys of intertidal coastline areas which could only be accessed by helicopter and took samples of any flotsam or debris which could have been hydrocarbons. None were found to have originated from the Montara spill.

The use of a vessel-supported helicopter proved an excellent survey methodology. Dr Duke reported "the operational logistics proved essential for the expeditious, effective and efficient conduct of aerial surveys aimed to both detect oil residues and comprehensively survey shoreline habitats".

They discovered the length of the shoreline which had mangroves and tidal wetlands was more extensive than anticipated. And they identified more than twice as many estuaries than were previously known.

The team also observed megafauna – dolphins, dugong, whales, turtles, crocodiles, sharks and rays – were common along almost the entire shoreline. There were more signs of turtle nesting than expected, based on the turtle tracks observed.

Consequences for fish in the Timor Sea

Several studies were conducted into the possible impact of oil on the local fish species.

Montara is situated in the commercially-important Northern Demersal Scalefish Managed Fishery, managed by the WA Department of Fisheries. Demersal fish live near the bottom of the ocean. There are 11 commercial fishing licences over the area, held by seven operators.

The WA Department of Fisheries studied the four main commercial fish species harvested in the area: goldband snapper; red emperor; saddletail snapper; and yellowspotted rockcod. They sampled fish from two affected areas and two non-impacted or control areas.

The tested samples were taken in November 2009 when there were visible oil slicks on the sea surface, with a second set trapped in January, 2010.

The key question was whether consumption of the fish posed a health risk to consumers. The conclusion was, "no detectable petroleum hydrocarbons were found in the fish muscle samples".

However, they pointed out the samples were taken after the oil stopped flowing. "Therefore these results only related to the sampling period and cannot be extrapolated directly to the period when oil was actively flowing".

It should be noted that, as a precautionary measure, the Department advised the commercial fishing fleet to avoid fishing in oil-affected waters.

Associate Professor Gagnon and Dr Rawson sampled demersal and pelagic fish, those which live near the surface. They sampled the fish four times for a study which aimed to determine the effects of exposure to Montara oil on commercial fish species:

- November 2009. This was three months after the spill began and immediately after oil spillage was halted. There was still some oil present at this time
- March 2010
- November 2010
- November 2011.

The results from November 2009, "indicated that in the short term, fish were exposed to, and metabolised petroleum hydrocarbons". But, they pointed out "limited ill effects could be detected in a small number of individual fish only, and no consistent adverse effects of exposure on fish health could be detected within two weeks following the end of the well release".

The main commercial species goldband snapper, red emperor, Spanish mackerel and rainbow runner were sampled to gain a more complete understanding of the biochemical and health status of fish in the Timor Sea.

They studied a range of physiological indicators, including fish condition factor or fattiness; the ratio of the liver size to the body size, which is a general indicator of chronic exposure to contaminants; and gonado-somatic index, a measure of reproduction.

They also looked at biochemical markers, which are sensitive indicators and more effective than chemical analysis in measuring the impact of contaminants like petroleum hydrocarbons on fish. These included liver detoxification enzymes which increase when exposed to contaminants; biliary polycyclic aromatic hydrocarbon (PAH) metabolites, a very sensitive indicator of exposure to petroleum hydrocarbons; liver integrity; and oxidative DNA damage.

They also conducted histological or microscopic examination of gonads.

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The fish had high biliary PAH metabolites, indicating uptake of petroleum, increased liver size and some increased DNA damage. No reproductive damage was observed.

The fish from close to Montara, trapped seven months after the spill began, showed continuing exposure to petroleum hydrocarbons. Red emperor collected within 37 kilometres of the spill site had enlarged livers and elevated oxidative DNA damage.

In fish collected a year later, November 2010, the differences between the fish trapped near Montara and the reference site fish had reduced and the fish were in a similar physical condition. Gagnon and Rawson said this suggested "a partial, ongoing trend towards a return to normal biochemistry/physiology following exposure to petroleum hydrocarbons".

Two years after the end of the spill, biomarker levels in goldband snapper and red emperor had mostly returned to reference levels, with the exception of the liver size, which was larger in fish collected close to Montara. The researchers stated "this could be related to local nutrient enrichment, or to past exposure to petroleum hydrocarbons".

Rawson and Gagnon also looked for olfactory taint in fillets from fish potentially affected by the Montara oil spill. A panel of eight to ten trained seafood sensory panellists assessed samples of raw and cooked fillets of red emperor and goldband snapper.

The olfactory assessment technique is very sensitive to taint by petroleum products, even when the level of contaminant concentration is so low it is considered acceptable in terms of food safety.

The fish tested for the olfactory study were trapped in November 2009, January 2010 and March 2010 and taken from nine locations.

The assessors were given no information about the fish and were asked to identify specific fish fillets only if there were differences between the portions and, in that case, to provide qualitative comments.

In the fish from the first sampling period, November 2009, there were some detectable olfactory differences between the red emperor samples collected less than four kilometres from Montara, and those collected from a non-impacted site 15n kilometres away. The difference was detected in both the raw and cooked samples. No distinctive taints, however, related to the presence of oil or dispersants were identified. The researchers said it was also difficult to say whether the assessors regarded the fish samples taken near Montara as being of better or worse quality than those collected further away.

There were no differences detected in the goldband snapper samples and the later red emperor samples.

Corals, reefs, banks and shoals

Dr Andrew Heyward from the Australian Institute of Marine Science led a study to investigate the effects of the Montara spill on:

- three reefs
- nine submerged banks and shoals
- the reefs', banks' and shoals' marine life.

His team found no obvious signs of recent disturbance at the closest land masses – Barracouta Shoal, 54 kilometres to the west, and Vulcan Shoal – six months after the spill and concluded the effect of the spill on fish was weak to negligible.

While there was widespread presence of oil at some sites, it was severely degraded and at several orders of magnitude lower than levels at which biological effects were possible.

Closer to Montara, species diversity and abundance declined and smaller fish declined in abundance. Heyward considered whether this could potentially be an effect of the spill, but resolved the observed variations "appear to be dominated by natural processes".

Heyward's team also studied the possible effects of the spill on fish and coral at Ashmore Reef, Cartier Island and Seringapatam Reef, which at 294 kilometres distant from Montara was far from the modelled oil trajectories and used as the control.

The first survey, in April 2010, provided no evidence of recent major disturbances in the coral communities of the reefs, "suggesting any effects of oil reaching these reefs were minor, transitory or sub-lethal and not detectable with the sampling methods used". This included no obvious patterns identified in the fish community surveys or in fish species richness, biomass and density.

There was evidence of a recent minor coral bleaching event in 2010, but this was worst at the most distant island and probably caused by higher water temperatures.

While there was no sign of oil on the sea surface around the reefs, laboratory analysis of sediment samples detected some hydrocarbons at all three reefs in 49 per cent of samples. This included the control site, Seringapatam Reef, which was not likely to have been impacted by the oil spill. These could have come from a number of sources, including naturally occurring oil seeps. The hydrocarbon levels were very low 'trace' concentrations, with higher levels at Ashmore and Cartier Reefs. The next year, 2011, hydrocarbons were found in fewer samples, 35 per cent, but concentrations were still higher at Ashmore Reef.

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Oil was observed at Ashmore Reef during the spill, but because the oil was so degraded it was not possible to accurately link it to Montara. The oil was well below the level at which it would be a risk to the environment.

Green sea turtle

Sea snakes and turtles

Dr Michael Guinea from Charles Darwin University led a team which studied the sea snake and marine turtle populations of the region. They focussed on six reefs: three which were potentially affected – Ashmore Reef, Cartier Island and Hibernia Reef, 56 kilometres north east of Ashmore – and four which were not likely to be affected: Scott Reef, Seringapatam Reef, Montgomery Reef and Browse Island.

The first survey in March 2012 was cut short due to bad weather. They surveyed again in March 2013. The team found no detectable impact of the spill on the sea snakes and marine turtles.

The sea snake population dynamics in the Timor Sea presented some mysteries. The sea snake population used to be the highest at Ashmore Reef, but it has been falling since 1998 and none have been seen there for some years. The two other reefs closest to Montara, Hibernia and Cartier Island, had the highest species diversity and the greatest number of individuals, while numbers declined between the two surveys on the more distant Seringapatam Reef.

The team reported marine turtle numbers appeared stable. However turtles from both Ashmore and the control Montgomery Reef showed elevated levels of bilirubin, a liver function indicator.

The researchers stated the cause of this elevation and its implications to the health of the turtles "remains unclear".

Studies on oil spills in the Arabian Gulf during the 1990s suggested sea snakes were the second most vulnerable species, followed by marine turtles, while sea birds were the most commonly reported casualties.

Birdlife on cays, shoals and reefs

Birds are at risk from an oil spill if they forage at sea, if they are a plunging species, or if they rest on the sea surface. Birds are top order predators, so anything which disrupts or limits food supply affects them. Any direct impact on the terrestrial habitat has the potential to contaminate breeding sites. Shorebirds foraging for invertebrates, like sandworms and crabs, face potential contamination through ingestion or soiling of feathers and, indirectly, through reduction in prey.

Dr Rohan Clarke, from Monash University, is studying the seabirds and shorebirds at Ashmore Reef, Cartier Island and Browse Island, 194 kilometres to the south west. Ashmore Reef, the largest of the three islands, is an ecological outpost, one of the most significant seabird breeding islands in the Timor Sea. It is a Ramsar-listed wetland with exceptional diversity. It hosts over 20 breeding species and is visited by 16 species of seabird or birds which spend most of their lives at sea, four herons and over 30 migratory shorebirds.

Clarke intends to conduct 10 surveys over five years, the minimum time needed to detect any trend in total numbers. The first was in April 2010 and the last is planned for November 2014. At the time of writing, seven surveys had been conducted. The visits take place twice yearly: in April when the maximum number of species is breeding and in November when migratory bird numbers peak.

Seabird numbers appear to be increasing on Ashmore Reef. In April 2010 there were 75,000 seabirds; in April 2012 the number had risen to more than 100,000 seabirds. In the following year the number had risen to more than 107,000.

On his first visit, eight months after the spill commenced, no sign of oil contamination was detected.

Clarke had done some earlier work on Ashmore Reef but there had been little work done on Cartier and Browse Islands. In fact, there had been almost no monitoring of seabirds in the north west of Australia until this study.

Tracking the oil spill and mitigating its impact

One of the Montara studies examined the use and impact of dispersants in mitigating the spill's impact. Spraying dispersants is a useful option to combat oil spills. AMSA commenced spraying dispersants on 23 August 2009, both from the air and by sea, finishing on 1 November. Dispersants were used within 22 kilometres of Montara and entirely within Australian waters.

AMSA reported the use of the dispersant, which had passed Australian laboratory acute toxicity testing requirements, was "highly effective in assisting the natural process of degradation and minimising the risk of oil impacts on reefs or shorelines".

Dispersants literally dissipate oil slicks, breaking them into water-soluble droplets which move from the surface into the water column. This hastens the degradation of the oil, but it does temporarily increase the hydrocarbon concentration in the treated water.

Dr King and Mr Gilbert studied 11 dispersant events. Their 3D studies found the chemical dispersant caused the hydrocarbon concentration in the water column to rise, with most in the top one metre. They found concentration was extremely localised and it reduced quickly with time, depth and distance from the dispersant site.

They reported the application of the dispersants had been proven to be efficacious, breaking up the hydrocarbons and facilitating them entering the water column and having less impact on the environment. They reported that after the use of the dispersant a World Wildlife Fund boat which was in the vicinity for four weeks following the spill was unable to report any animals perishing due to the oil spill.

Scientists and engineers worked together to develop a new methodology for tracking the spill and studying its fate. The methodology used to track the spill for its duration provided a detailed, comprehensive and unprecedented understanding of the fate of the oil. It determined what areas had been affected and identified untouched areas which scientists could use as control sites when they examined the impact of the spill on the local wildlife.

This methodology is now widely used in the oil and gas industry when companies develop environmental plans and oil spill contingency plans.

Scientists were able to study the impact of spills of light oil on the environment in the Montara research. Most oil spills are of heavy oil; but light oil, such as that from Montara, evaporates more quickly and is more water soluble.

The research generated new data on the impact of oil spills in a tropical environment; collected baseline data for measuring the impact produced formation water discharge – which is generated during the process of oil and gas extraction from the subsurface – could have on the environment; and contributed to the knowledge of the exposure of fish to naturally occurring hydrocarbons from the abundant naturally occurring oil seeps in the Timor Sea.

All this will undoubtedly increase the industry's preparedness to manage a future maritime adverse event. This research will also have an international impact, setting the benchmark for managing an oil spill in a remote and environmentally significant region.

A voyage of discovery and its positive scientific legacy

The Montara Environmental Monitoring Program has provided an unprecedented opportunity for scientists to study this little known area of the Timor Sea.

This voyage of discovery produced an abundance of new science on the waters, wildlife and habitats of the region. Because of its remoteness, there had been little research previously undertaken in the area: even the north west coastline of Australia had never been so precisely mapped.

The area is changing. Rainfall has increased over the past 50 years; the area covered by mangroves has grown; storms are becoming more severe and more damaging; and the biodiversity and the number of species are expected to change.

This body of scientific research will be important in maintaining and protecting the unique environmental diversity of the region. It will also be used as reference material when future oil and gas exploration is being considered. The Timor Sea might be remote, but as a result of this work by some of Australia's leading scientists and their support teams, it is now much better known.

The impact of their findings will be felt from scientific research institutions to the oil and gas industry and the ports sector, and from Australian government authorities to interested Australian and international communities. The true value and effect of this enormous new body of knowledge, however, will only be realised over many future years as it embeds itself into how the region is perceived, understood and managed by its complex array of stakeholders.

Asa Wahlquist has been writing professionally about science for nearly 30 years. She has been published in The Australian, The Sydney Morning Herald and The Land; and featured on ABC Radio and Television. Asa has won many awards, including a Walkley Award for Rural and Regional Journalism and a Eureka Prize for Environmental Journalism. She has published a book about Australia's water crisis, described by Australian of The Year, Professor Tim Flannery, as, "A brilliant and incisive account of one of the most pressing issues of our time". Asa has a Bachelor of Agricultural Science and a Master of Science preliminary in Biological Sciences.

Sooty tern in flight

Shoreline ecological assessment aerial surveys

James Cook University

TropWATER - Centre of Tropical Water and Aquatic Ecosystem Research

Dr Norm Duke, with the University of Queensland at the time of this research and now with James Cook University, led aerial and ground surveys of coastal shoreline habitat in regions potentially exposed to the Montara oil spill in north west Australia.

An example of coastline located between York Sound and Brunswick Bay

OVERVIEW

The primary objective was to determine any exposure of waters, sediments, fauna or flora to oil and, if detected, quantify the level of that exposure.

Further objectives of the research surveys were to:

1. quantify the presence of megafauna, such as dolphins, turtles and dugongs, in the subject area before potential oil spill impact in order to determine their level of potential exposure to oil
2. quantify the presence and extent of communities or habitats including mangroves, other tidal wetlands and other shoreline types, in the subject area pre-impact in order to determine the level of potential exposure to oil
3. record pre-impact condition of communities or habitats, such as dieback and bare areas, in the subject area
4. quantify the actual area or the extent of any observed effects of oil impact on habitats or communities in the subject area in order to determine the level of potential exposure
5. determine any residual exposure of waters, sediments, fauna or flora to oil and, if detected, to quantify the level of exposure
6. quantify the area or extent of recovery from any harmful effect of oil impact on habitat or communities in the subject area.

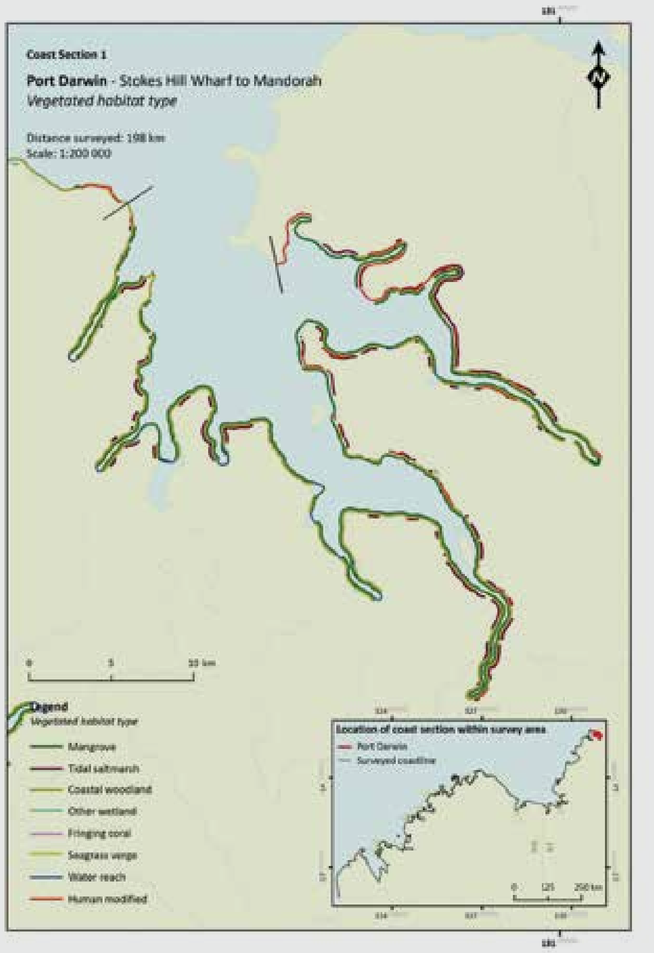
Of these further objectives, only the first three were acted upon as no oil was detected along the surveyed shoreline from Darwin to Broome.

The research survey began in Darwin on 9 November, 2009 and ended on 18 November, 2009 in Broome. It generated a report which gives a detailed compilation of coastal shoreline habitats of 5,102 kilometres of shoreline.

The shoreline was surveyed, analysed and mapped to provide spatial and quantitative characterisation of vulnerable coastal ecological features:

- mangroves, the most vulnerable coastal habitat present, grow along 63% of the shoreline, covering over 3,200 kilometres
- saltmarsh occurs on more than 1,200 kilometres of coastline, or about 24% of the survey region
- the coastline is rocky for 2,763 kilometres, or about 54% of the shoreline
- for the shoreline, 9,441 kilometres^2 of tidal wetland, in the form of mangrove and saltmarsh, was observed (OzCoasts 2009). This is 1.85 kilometres^2 of tidal wetland for every kilometre of shoreline surveyed.

This was the first time a survey of this nature had been undertaken.



Physical characteristics of the Port Darwin survey region

Elements of the methodology for research data collection included:

- aerial surveys, mainly using a helicopter employing high definition digital video and still cameras
- video footage, which was used to categorise the entire surveyed shoreline into 16 subregions, including classification of representative classes of type and condition
- on-ground surveys of intertidal coastline areas, accessed by helicopter
- biological analysis of waters, sediments, flora and debris.

The method of gaining data, a combination of video and still cameras from a helicopter at 200-300 metres in altitude, was in itself innovative and had not been applied previously. This provided a set of oblique images of the shoreline, complementing satellite and ground-generated imagery. This methodology is now being applied by other scientific studies.

The use of a vessel-supported helicopter proved an excellent survey methodology. Its utilisation allowed for close inspection of any notable flotsam or debris suspected of being hydrocarbon in origin. It was also possible to collect samples of any bloom-like debris directly from the helicopter.

Additionally, the full coastline surveying approach generated a depth of data – 50-60,000 images – not possible to attain through 'spot' single location checks. The data provided a greater degree of insight into the 5,000 kilometres plus of coastline region than previously existed.

Because it is one the most isolated areas of Australia, data for the surveyed region was scarce. The comprehensive digital library of geo-referenced photographic imagery from this study, and the report itself, present the most comprehensive database of habitat type and condition for this area to date. This data provides valuable information to gauge future changes to the environment in this remote area of Australia.

(Top to bottom) Two HD video cameras were used during aerial surveys; Coastline located between Cape Ford and Pearce Point; Coastline located between York Sound and Brunswick Bay; Selected helicopter landings enabled sampling and verification of ground conditions

KEY RESEARCH FINDINGS

The research identified no oil slicks or oil contamination during the survey, nor was any impact observed on the environment which could have feasibly been the result of the Montara oil spill. A significant amount of flotsam and bloom-like debris was observed, but analysis suggests this was biotic, either naturally occurring or the result of agitated tidal flows.

In addition to findings related specifically to the Montara spill, research undertaken in this study has:

- generated a permanent baseline record of shoreline/intertidal habitats and their condition in the region. This was the first time a study of this nature in the region had occurred. Its findings will help calibrate and understand impacts associated with future large-scale disturbances in tidal wetlands, whether man-made, for example from oil spills, or naturally occurring from events like cyclones. Wetlands are common across the survey region. This data has been enhanced by surveys of mangrove species in two locations, which can be compared with species available for the region
- discovered the amount of this shoreline with mangroves and tidal wetlands is much more extensive than anticipated
- identified significant diversity and numbers of marine megafauna in the area. The type of megafauna observed included dolphins, dugong, whales, turtles, crocodiles, sharks and rays
- determined signs of greater than anticipated turtle nesting activity on York Sound, based on observed turtle tracks. This has provided a potentially valuable contribution to the knowledge of turtle nesting activity along this coastline
- identified more than twice the number of estuaries in the surveyed region than previously known. Prior to this study occurring, a large number of estuaries were poorly known or described. This is of considerable commercial importance because of the association between estuaries and fisheries. Estuaries are sources of abundant marine life. The diversity of marine life also increases in and near estuaries. They also impact on terrestrial species numbers and diversity.

The study identified significant diversity and numbers of marine megafauna in the area, such as dolphins, dugong, whales, turtles, crocodiles, sharks and rays. Greater than anticipated turtle nesting activity was also observed on York Sound.

'RV Flamingo Bay', the support vessel used in aerial surveys

An example of coastline in Port Darwin

RESULTS DISCUSSION

Marine megafauna

Marine megafauna sightings were common along almost the entire shoreline. All identified species are highly vulnerable to oil spill damage should oil come in direct contact with the animal. In addition, a number of these species, such as dugoing and sea turtles, rely on seagrass and coral reef communities as foraging ground, increasing the risk of impact from oil spill to these species. Others, including dolphins and sharks depend on coastal fisheries as food sources.

If it occurred, oil damage to mangrove communities would have further consequences for these species due to the utilisation of mangrove systems by juvenile fish as nursery grounds (Nagelkerken, et al. 2000).

Reduced numbers of high quality fish prey has been noted following past oil spills (Irons, et al. 2000). It is highly likely oil spill damage to mangrove communities along this coastline would result in a reduction of forage fish abundance in the longer term. The greatest concentrations of megafauna, 60% of those observed, were recorded in the area from Cape Londonderry to Admiralty Gulf. The majority (67%) of megafauna sightings were of turtles.

Frequency and types of observed fauna varied considerably from one section of coastline to the next. Some of this variation may be attributed to biotic preferences but weather conditions influencing turbidity, time of day affecting light, tidal condition affecting exposure, as well as currents and rain squalls, could have significantly affected how much fauna could be observed.

Tidal flux at the mouths of large river systems commonly resulted in high turbidity and, hence, decreased visibility. These conditions may have resulted in underrepresentation of fauna counts during surveys.

The frequency and types of observed fauna varied considerably from one section of coastline to the next…this variation may be attributed to biotic preferences, weather conditions, turbidity, tides and currents.

Habitats present in shoreline ecological assessment

Tropical and subtropical mangrove habitats are considered to be particularly vulnerable to damage from hydrocarbons, making this study of particular value to the oil and gas industry.

The permanent digital imagery record of current habitat condition generated through this study will allow future comparisons of ecosystem health and condition, should the need arise. If affected, shoreline biota and habitats could continue to be monitored to assess the extent and duration of any damage.

While tidal wetlands dominated the surveyed region, saltmarsh and salt flat habitats were common along the intertidal region, spanning more than 1,215 and 1,317 kilometres respectively.

One of mangroves' scientific values is that they help quantify changes in habitats. Healthy mangroves, for instance, mean a healthy catchment, as they are the literal filter of water/rain/etc from their entire catchment area.

Measures for each region of tidal wetland quantified the coastal shorelines at greatest risk. Three coastal areas at greatest risk, because they have disproportionately vast tidal wetland areas, are the Joseph Bonaparte Gulf, Cambridge Gulf and King Sound.

In the survey region, the range of mangrove species are progressively limited to the west. Species endpoint occurrences are recognised as limits of existence where such species are at high risk from further disturbance (Duke, et al. 2007), such as an oil spill (Duke, et al. 2000).

Respective coastal areas at greatest risk in having western species limits include the area west of Darwin and the area around King Sound.

It is underappreciated how profoundly mangrove ecosystems respond to change. In fact, they are indicators of change, in context of both activity upstream and downstream of them. Healthy mangroves mean a healthy catchment, as they are the literal filter of water, such as rain and irrigation run-off, from their entire catchment area.

One of their scientific values, therefore, is that they help quantify changes in the habitat.

The extent of intertidal habitats vulnerable to oil spill damage within the Montara oil spill region is extreme. These intertidal communities are essential to the maintenance healthy fisheries (Nagelkerken, et al. 2000; Duke, et al. 2007).

Weather impact on the region

The research identified important areas clearly damaged by cyclones, providing an opportunity to examine the localised nature of storm damage. There was, however, minimal impact from lightning observed.

Clarifying this damage as being caused by storms, and hence naturally occurring, makes it easier to confirm what an oil spill did or didn't cause. As such, this information is of vital importance to the oil and gas industry, as well as governments and regulators in managing these natural resources.

It is also significant because storms are becoming more severe and damaging in the region. It can be expected there will be more naturally occurring destructive environmental impacts. Storms need to be quantified to understand their influences over time on mangrove replenishment. They have elaborate processes to replenish themselves, but when environmental conditions become too severe their ability to do so will be significantly diminished.

Coastline located between Mandorah and Point Blaze

ShoreView and MangroveWatch

Dr Duke is developing ShoreView, a visualisation application, the prototype of which – funded by PTTEP AA – was developed concurrently with the Montara research study. Ultimately, the objective is to present a publicly accessible online environment of Australian coastal habitats, including sequential imagery and data for viewing multiple time periods of any location. In Australia, with the MangroveWatch program (see: www.mangrovewatch.org.au), there are more than 500 trained and equipped observers as committed contributors, with geo-referenced continuous imagery of around 8,000 kilometres of coastlines covered so far, with many locations filmed multiple times, observing disturbances such as flooding events and severe storms.

Climate change impact

Climate change impact was also observed through the research program. An example of this was the clear evidence of mangrove expansion, prompted by increasing rainfall in this region over the past 50 years. Obverse to the east coast of Australia, which is getting drier, the northern regions of Australia are becoming wetter. It should be noted mangroves take a few years to react to variations in climate.

As rainfall increases in this part of the country there will be impacts on the diversity and numbers of species. Species that do not have a foothold here will, in some cases, be able to establish themselves. This includes invasive species and/or those from nearby Indonesia. This could impact on mangrove biodiversity, which would in turn impact on current balances occurring in nature across this region.

Mangrove shorelines are vulnerable as they also provide stocks of carbon buried below ground. There is five to six times more buried carbon associated with mangroves than trees on dry land. Freshwater wetlands are similarly valuable in this context.

Mangrove shorelines are vulnerable as they also provide stocks of carbon buried below ground. There is five to six times more buried carbon associated with mangroves than trees on dry land. Freshwater wetlands are similarly valuable in this context.

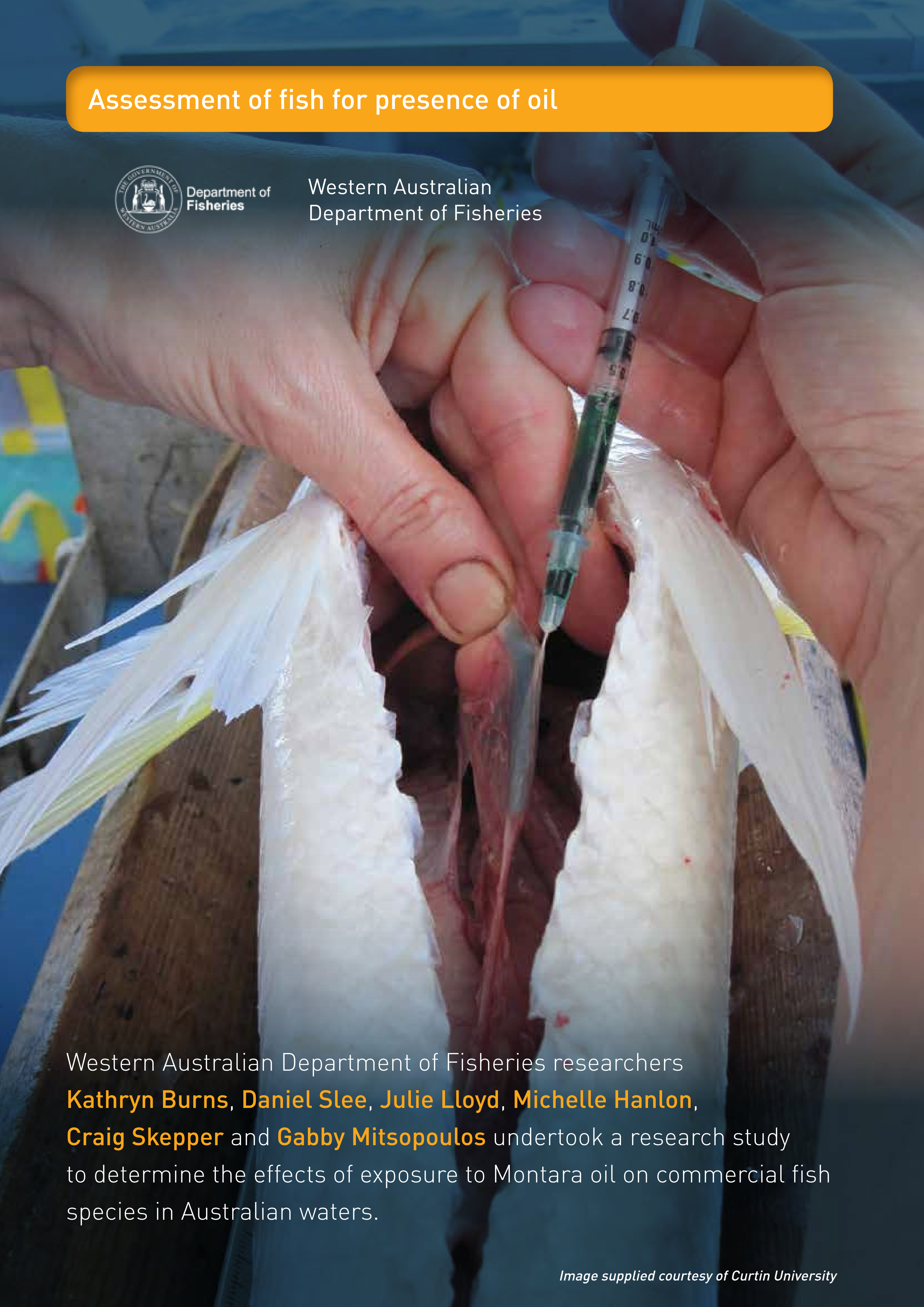
As sea levels rise, the intertidal areas containing mangroves are threatened and mangroves may therefore be lost. This would increase the CO2 in the atmosphere, which in turn increases global warming. Of further concern is mangroves protect the shoreline, whether from storms, tsunamis or oil spill, so their diminishment could have further environmental repercussions.

'RV Flamingo Bay', the support vessel used in aerial surveys

This discussion was based on the S2 Shoreline ecological assessment aerial surveys research study, but was enhanced by extensive discussions with James Cook University's Dr Norm Duke. PTTEP AA is grateful to Dr Duke, James Cook University and the University of Queensland for their contributions to this report. The full list of the study's authors is: Norm Duke, Apanie Wood, Kim Hunnam, Jock Mackenzie, Alex Haller, Nicola Christiansen, Katherine Zahmel and Tim Green.

All images in this discussion supplied courtesy of Dr Norm Duke.

Assessment of fish for presence of oil



Department of Fisheries

Western Australian
Department of Fisheries

Western Australian Department of Fisheries researchers **Kathryn Burns**, **Daniel Slee**, **Julie Lloyd**, **Michelle Hanlon**, **Craig Skepper** and **Gabby Mitsopoulos** undertook a research study to determine the effects of exposure to Montara oil on commercial fish species in Australian waters.

Image supplied courtesy of Curtin University

OVERVIEW

The fish species which were the subject of this research were those targeted by the Northern Demersal Scalefish Managed Fishery (NDSMF). Demersal fish live on or near the seabed.

The waters of the NDSMF are defined as all Western Australian waters off the north coast of Australia east of longitude 120° E. These waters extend 370 kilometres, out to the edge of the Australian Fishing Zone limit under the Offshore Constitutional Settlement arrangements. The total gazetted area of the fishery is 483,600 kilometres^2.

The study aimed to determine if targeted fish had been exposed to hydrocarbons and whether consumption of fish from the affected areas posed a health risk. This study focused on consumer health issues.

Four key NDSMF species were targeted, goldband snapper, red emperor, saddletail snapper and yellowspotted rockcod.

Fishing was undertaken using standard commercial techniques within the impacted and non-impacted 'control' areas.

The initial spill occurred in a commercially important area of the NDSMF. This fishery is managed by the Western Australian Department of Fisheries through Offshore Constitutional Settlement arrangements in place with the Australian Government. Other offshore fisheries, such as the Mackerel Interim Managed Fishery and the Northern Shark Fishery also occur in the area.

Recreational species such as sailfish also exist in this area. Fishing effort for these species, however, is low in these waters compared with the NDSMF fishery. This study, therefore, concentrates on premium value commercial species targeted by the NDSMF.

Where possible, sampling sites were chosen to replicate those sampled by Curtin University for the Montara Environmental Monitoring Program S4A study in their initial survey in November 2009. Consideration was also given to ensuring sites were selected where oil had been observed over the longest period and during the later period of the spill.

Unfortunately, in the period between surveys, Curtin University's control (unaffected) sites had become contaminated with hydrocarbons and therefore it was not an option to use these sites as originally planned.
The alternative control sites for this study were identified using all available information including Department of Fisheries situation reports, satellite images and modelled data provided by PTTEP AA.

Two sites were chosen from the affected area and two sites within the control area.

The sampling trip for this study was undertaken from 9 to 19 January 2010.

Additional muscle and gut samples, collected by Curtin University from 9 to16 November 2009, during a sampling trip for monitoring study 4A Assessment of effects on Timor Sea Fish, were incorporated into this study.
The Curtin study's samples were collected during a period when there was a quantity of visible hydrocarbons on the water surface and were collected in an identical manner to those collected during this S3 Assessment of fish for presence of oil study.

Image supplied courtesy of Curtin University

KEY RESEARCH FINDINGS

This study concluded, from the two samplings, no detectable petroleum hydrocarbons were found in the fish muscle samples.

In 2002, The US National Oceanic and Atmospheric Administration published a report 'Managing seafood safety after an oil spill' (Yender, et al. 2002). The study identified tissue concentrations of polycyclic aromatic hydrocarbons (PAHs) and their persistence in various marine organisms analysed after several ship grounding oil spills. The various fish analysed in this study contained PAHs at the low end of the Yender study's range and within the environmental background levels found in some areas in other countries.

These samples, however, were not taken while the oil was flowing. The Curtin University field trip was almost one week after the uncontrolled release of oil from Montara had ceased and the Department of Fisheries field trip occurred two months after this time. These results, therefore, only relate to the sampling period and cannot be extrapolated directly to the period when oil was actively flowing.

As a precautionary measure to ensure consumer safety, the Department of Fisheries advised the commercial fishing fleet to avoid fishing in waters affected by oil and it is the Department's understanding commercial fishers voluntarily complied with this advice.

Capturing fish for scientific study near Montara
Image supplied courtesy of Curtin University

DISCUSSION

Studies by Burns, et al. (2001, 2004) on the Australian North West Shelf and in the Gulf of Papua have demonstrated rapid transport of petroleum hydrocarbons through the oceanic water column to the sediments. This rapid transportation is often mediated by hydrocarbon-degrading microbes, which in turn are a food source for zooplankton.

Therefore some oil is likely to have settled to the sea bed in the faecal pellets from zooplankton. Conover (1971) estimated zooplankton settled about 20% of the Bunker C oil, near Chedabucto Bay in Canada into the coastal sediments, spilled from the Tanker 'Arrow'.

A detailed study around the Montara area in 2005 measured hydrocarbon fluxes, the rate at which hydrocarbons migrate to the surface, in sediment traps of PAHs through the stations at the shelf break of 500 metres and at the 90 metre station near the platform (Burns, et al. 2010). These measured fluxes were from naturally occurring seabed oil seeps and the ordinary activities of the marine industries. In the instance relevant to this study, given the attendant volume of oil on the sea surface, it would be expected the flux rates would be orders of magnitude higher than those measured in the Burns et al study.

No detectable petroleum hydrocarbons were found in the fish muscle samples from this study.

Polycyclic aromatic hydrocarbons are potent atmospheric pollutants. They can cause cancers, mutations and/or physiological abnormalities.

It has been known for many years that fish are able to initiate or increase the production of enzymes for clearing their tissues of petroleum hydrocarbons (Burns, 1976 and many others since). A study around the Hariet A production platform on the North West Shelf of Australia, which was discharging produced formation water with known oil content, showed fish living nearby had significant levels of hydrocarbon degrading enzymes (Codi-King, et al. 2005).

Hydrocarbon degrading bacteria have also been found in the liver and bile of fish from the North West Shelf (Johnson, 2001; Codi-King, et al. 2005). These studies on the ability of fish to degrade oil could account for the fact none of the fish in this study had petroleum hydrocarbons in their tissue above the analytical detection limits.

This discussion was based on the S3 Assessment of fish for presence of oil research study. PTTEP AA is grateful to study researchers Kathryn Burns, Daniel Slee, Julie Lloyd, Michelle Hanlon, Craig Skepper, Gabby Mitsopoulos and the West Australian Department of Fisheries for their contributions to this report.

Olfactory analysis of Timor Sea fish fillets

Curtin University

Curtin University
Department of Environment
and Agriculture

Curtin University researchers **Dr Christopher Rawson** and **Associate Professor Marthe Monique Gagnon** led a study into the presence of olfactory taint in fish fillets from fish potentially affected by the Montara oil spill.

The study constituted an important component of the Montara Environmental Monitoring Program

OVERVIEW

Olfactory assessment of seafood has been established as a sensitive technique for identifying taint by petroleum products, even when the level of contaminant concentration is so low it is considered acceptable in terms of food safety.

Fish don't accumulate hydrocarbons in the flesh. Like most vertebrates, fish metabolise then eliminate the hydrocarbons. This process will generally take fish about two weeks to complete.

The rationales for this study being undertaken were:

- the importance of ensuring the public was protected from purchasing, then consuming, any fish negatively impacted by hydrocarbons
- ensuring the integrity, viability and reputation of the Northern Demersal Scale Fishery, from which the fish samples were taken. The study focussed on the commercially important red emperor *(Lutjanus sebae)* and goldband snapper (*Pristipomoides multidens*).

Surveys collecting the fish were undertaken by ecotoxicologists from Curtin University and, separately, personnel from the Department of Fisheries, Western Australia.

Fish used in the study were captured in November 2009, January 2010 and March 2010 and were collected at nine different locations in the Timor Sea at sites designated as 'impacted' and 'non-impacted'. This designation was based on the known location of hydrocarbons during the well release. Impacted samples were collected from fish captured within 37 kilometres of Montara and non-impacted samples were collected from fish samples taken from locations further than 148 kilometres distant.

A panel of eight to ten trained seafood sensory panellists from the seafood industry was used to assess the samples.

Panellists were asked to distinguish between samples randomly selected from the sets of fillets from fish captured in impacted and non-impacted locations. The trial was run with raw and cooked samples. The panellists were:

- not aware of the origin of the test material
- only requested to identify specific fish fillets if differences existed between the portions
- asked to provide qualitative comments on the olfactory qualities of the samples if a difference existed between portions.

By allowing assessors to submit qualitative comments, any consistent descriptors might have provided an indication of possible source(s) of specific odours. Additionally, by using samples from different sampling periods it was expected any persistence of olfactory taint would be identified.

Research undertaken in this study has collected valuable data on the olfactory characteristics of the commercially important red emperor and goldband snapper species.

KEY RESEARCH FINDINGS

Key research findings include:

- there were some detectable olfactory differences between red emperor samples at impacted and non-impacted sites from the first sampling period (November 2009). The differences were detected in both raw and cooked samples
- no distinctive taints relevant to detectable olfactory differences were recognised during the study which could be related to the presence of oil or dispersants
- no olfactory differences were identified between goldband snapper collected from impacted and non-impacted sites in any of the sampling periods
- no differences were identified between impacted and non-impacted samples of either species collected later (January 2010 and March 2010)
- qualitative descriptions of observed differences in sample odours showed no consistent trend.

Red emperor and goldband snapper are important commercial fish species which were studied


Each fish selected for analysis was initially assessed for length

DISCUSSION

Methodology

The olfactory testing methodology is a well-established and scientifically accepted means of assessing the impact of chemicals in food. It is widely used in assessing post-harvest food quality and has been adopted as a means of detecting taint in seafood following oil spills.

Cooked and uncooked samples were tested as cooking can sometimes reveal different contaminants. Some components of crude oil are quite volatile and can be removed by cooking. Additionally, the cooking process can reveal the presence of contaminants.

The testing was conducted using the standard duo-trio method (Standards Australia, 2005). The panellists are seafood industry employees recruited, then trained, at Curtin University in the sensory evaluation of seafood quality parameters. Panellists were given no information about the samples they were testing in order to prevent the development of false expectations and/or introduce bias into the evaluation.

The duo-trio test is an overall difference test which determines whether or not a sensory difference exists between two samples. This method is particularly useful to determine whether:

- product differences result from a change in ingredients, processing, packaging or storage
- an overall difference exists – in this case odour – where no specific attributes can be identified.

Results

Given all samples were collected, handled and stored similarly, any detected odour differences between the impacted and non-impacted red emperor fillets are likely to be due to site-specific characteristics at the time of capture.

It was difficult to interpret the descriptors used by the panellists as positive or negative. As a result, it was problematic to ascertain whether panellists regarded the fish samples collected in the impacted area as being of better or worse quality than the fish samples originating from non-impacted areas. The testing protocol does not allow for the researcher to ask the panellists for further information on their comments. This is to avoid confounding bias, or introducing another variable which could distort the outcome.

It is not possible to conclusively identify the source(s) of these olfactory differences.

Because of the lack of consistent descriptors, olfactory differences detected in fish between sites could be explained by:

- variations in food sources
- biological age of the animals
- home range. A species with a small home range will be continually exposed to a pollution event over a long period, for example over the course of this study. A species with a large home range may be exposed to the source of pollution for a short period, but then move to an area that is not subject to the pollution
- physical activity surrounding the normal operations of the drilling rig
- temporary intensive marine activity immediately following the Montara oil spill (but not associated with exposure to oil).

Red emperor and goldband snapper are species which live in relatively deep waters of up to 200 metres. There was some indication, from perceptions of tainting, red emperor in the vicinity of the drilling rig were impacted by the Montara spill. However, this research suggests the Montara oil has not caused persistent detectable taint in the fillets of either species.

This research suggests the oil has not caused persistent detectable taint in the fillets of either species.

The FV Megan M was used in some of the research studies

This discussion was based on the S3A Olfactory analysis of Timor Sea fish fillets research study, but was enhanced by extensive discussions with Curtin University's Associate Professor Marthe Monique Gagnon and Dr Christopher Rawson. PTTEP AA is grateful to Associate Professor Gagnon, Dr Rawson and Curtin University for their contributions to this report.

All images in this discussion are owned and supplied courtesy of Curtin University.

Assessment of effects on Timor Sea fish

Curtin University
Department of Environment and Agriculture

Curtin University researchers **Associate Professor Marthe Monique Gagnon** and **Dr Christopher Rawson** undertook a four-phase monitoring study on demersal and pelagic fishes in Timor Sea waters affected by the Montara oil spill. Its objective was to determine the effects of exposure to Montara oil on commercial fish species in Australian waters.

A juvenile red emperor

OVERVIEW

The research study aimed to:

- characterise any exposure of selected fish species to petroleum hydrocarbons
- evaluate if fish health, including reproductive health, had been impacted by exposure to petroleum hydrocarbons
- investigate any long-term trends in physiological indices and biochemical marker (biomarker) levels on selected fish species from impacted and reference areas
- gain a more complete understanding of the biochemical and health status of fish in the Timor Sea
- establish baseline data for monitoring following the commencement of produced formation waters, which is water extracted with oil, being discharged at the location of the future oil and gas facility.

The sampling targeted the commercially important demersal species, which live near the bottom of the sea, goldband snapper (*Pristipomoides multidens*) and red emperor (*Lutjanus sebae*) and the pelagic species, which live near the surface of the sea, Spanish mackerel (*Scomberomorus commerson*) and rainbow runner (*Elagatis bipinnulata*).

Timings of the sampling, which collected a total of 1,662 fish, were:

- November 2009 (Phase I – approximately two weeks after the oil spill event ceased)
- March 2010 (Phase II – approximately seven months after the spill event began)
- November 2010 (Phase III – approximately 15 months after the spill event began)
- November 2011 (Phase IV – approximately 27 months after the spill event began).

Each of the four discrete sampling programs surveyed, primarily, the same sites. In Phase IV, samples were also taken from five additional sites. This occurred so as to more closely investigate additional areas previously sampled by other research programs, as well as to improve the data set's statistical power

Physiological indicators on which the researchers focused included fish condition factor, liver somatic index (LSI) and gonado-somatic index (GSI). The biochemical markers, selected for their relevance to exposure to petroleum hydrocarbons, were liver detoxification enzymes, biliary polycyclic aromatic hydrocarbon (PAH) metabolites, liver integrity and oxidative DNA damage. In addition, histological examination of the cells and tissues of the gonads was performed.

Why biomarkers?

The most relevant and sensitive assessment of petroleum hydrocarbon exposure and effects on fish is through the use of biochemical markers of fish health. Biomarkers are biological endpoints such as liver detoxification enzymes and gonad development which can be used to inform on exposure or effect.

Biomarkers are a more effective means than chemical analysis of measuring the impact on fish of contaminants, such as petroleum hydrocarbons. In fact, fish depurate or eliminate petroleum hydrocarbons within a few weeks following cessation of exposure. Previous exposure to petroleum hydrocarbons, however, can be determined by the measurement of physiological and biochemical reactions to the contaminants through biomarker investigation.

No single biomarker can give an overall assessment of fish health and, consequently, a suite of biomarkers is measured on each individual fish. These include measuring the metabolites of polycyclic aromatic hydrocarbons in the bile of the fish, estimating the amount of oxidative DNA damage which has occurred, measuring the activity of liver detoxification enzymes and measuring liver integrity.

KEY RESEARCH FINDINGS

Studies conducted in the areas affected by the Montara oil spill showed that two years following the well's uncontrolled release of hydrocarbons, physiological parameters – as well as biochemical markers of fish health – showed a return towards reference levels for fish captured close to the rig location.

While the one exception was liver size, which varied between impacted and reference areas, liver integrity was preserved at all times for all four species of fish collected.

Initial sampling results also indicated that in the short-term fish were exposed to, and metabolised, petroleum hydrocarbons, but no consistent adverse effects on fish health or on their reproductive organs were detected.

In sampling undertaken approximately seven months after the spill event began, continuing exposure to petroleum hydrocarbons was evidenced by elevated liver detoxification enzymes and PAH biliary metabolites in three out of four species collected close to Montara. Additionally, red emperor collected close to the oil rig had enlarged livers and elevated oxidative DNA damage.

No reproductive impairment or structural alteration of gonadal tissues were observed in any of the species up to a year following the end of the well release.

Analysis suggested overall differences between sites across all biomarkers were influenced mainly by biomarkers of exposure to petroleum hydrocarbons.

Further, these analyses suggest as the time post-release increases, the overall biomarker signals from exposed and reference sites appear to converge.

Overall, fish collected on November 2009 and March 2010 initially showed evidence of exposure to petroleum hydrocarbons at sites close to the Montara well head, increased liver size and occasionally, increased oxidative DNA damage. While at some sites differences in biomarker levels were still observed one year after the end of the well release, the magnitude of the differences had reduced relative to earlier samplings, suggesting a partial, ongoing trend toward a return to normal biochemistry/physiology following exposure to petroleum hydrocarbons.

Studies conducted two years following the control of the oil spill determined the magnitude of the effects resulting from the spill, relative to reference areas, had reduced. This suggests:

1. an ongoing trend towards background reference conditions at all sites
2. negligible ongoing impact on fish health as measured by physiological and biochemical markers
3. fish health has been minimally impacted, allowing the continuation of commercial fishing to safely occur.

In addition to findings related specifically to the Montara oil spill, research undertaken in this study has:

- collected valuable baseline data on the Timor Sea environment. This is important for commercial fishing and for the oil and gas industries, as well as the regulators involved in environmental management and the Australian Government. It will help determine if future instances of environmental impact, such as oil spills and cyclones, adversely affect fish health and it will contribute to regulatory and monitoring regimes
- identified even if their habitat is 100 metres below the water, some fish are still impacted by oil spills because a portion of petroleum oil is water-soluble
- generated new data relevant to the impact where releases of 'light' oil, such as that from Montara, can have on the environment. This includes potential temporal and spatial impact. Most oil spills are of heavy oil. Light oil evaporates more quickly but is more water soluble than heavy oil
- collected data which represents a baseline for measuring the impact produced formation waters discharge could have on the environment. Fossil waters are extracted simultaneously with crude oil from the undersea reservoir during the extraction process, after which oil and water are separated. This water, known as produced formation water, is usually discharged back to the ocean. The discharge is continuous and contains some petroleum hydrocarbons, so must be carefully managed
- contributed to the knowledge of the exposure of fish to hydrocarbons from naturally occurring, and abundant, oil 'seeps' in the Timor Sea
- provided important information on the natural variability of physiological measurements and biomarker levels which can be expected in the absence of contamination.

This study generated new data relevant to the impact which releases of 'light' oil, such as that from Montara, can have on the environment. This includes their temporal and spatial impact. Light oil evaporates more quickly than heavy crude and is more water soluble than heavy oil.

DISCUSSION

Sampling for the final phase of the study was conducted two years after the end of the hydrocarbon release. This study determined both species of fish appeared in good physical condition. Overall, fish collected at the four sites closest to the rig, all located within 148 kilometres from the well head, showed no recent exposure to petroleum hydrocarbons.

Goldband snapper collected at the sites closest to the rig were of similar size to those originating from a reference site, while red emperor collected close to the rig were of smaller size relative to their counterparts collected from a reference site.

While goldband snapper has a relatively rapid growth rate and did not show population size differences, red emperor is a slow growing fish. The smaller size observed in red emperor collected close to the rig is likely due to its slow growing characteristics and recent fishing pressure experienced by the population at this location. A difference in fish size has not been observed in previous samplings. It could, however, also be a long-term impact of the oil spill.

While the physical condition of the fish of both species was good at all sites, the liver size relative to body size of both species of fish remained elevated for a few individual fish from sites closest to the rig. However, other biomarkers of exposure such as liver detoxification enzymes, PAH biliary metabolites and oxidative DNA damage were comparable between fish collected close to the rig and fish originating from the reference sites. This confirmed uptake of petroleum hydrocarbons had not occurred in the recently preceeding weeks.

The November 2011 sampling found the liver size relative to body size in the fish collected close to the well head was larger compared to fish originating from a reference site. This could be related to local nutrient enrichment, or to past exposure to petroleum hydrocarbons. Liver size to body size is a long-term indicator of exposure to pollution. This specific biomarker might take a longer time to return to reference levels. Future monitoring will indicate if the higher liver size relative to body size in fish collected close to the well head has returned to reference levels.

For male and female individuals of both species, the gonad size relative to body size of adult fish collected close to the rig were similar to those collected at the reference site, as were the stage of egg maturation within the female gonads.

Condition factor

The condition factor of fish provides information on the general health status and energy reserves of individual specimens. It might be affected by non-pollutant factors such as seasons and nutritional levels (van der Oost, et al. 2003).

The condition factor of fish collected in November 2009 and March 2010 were similar between reference and impacted zones. This result suggests, despite the presence of petroleum hydrocarbons in their environment, the impacted zone fish had an adequate food supply to maintain a body condition similar to the fish originating from the non-impacted areas.

The Cornea Seep

Of particular interest were the fish collected in the vicinity of the Cornea Seep, a naturally occurring oil seep at Heywood Shoal. In early phases of this monitoring program, a few individuals returned positive biomarkers of exposure to petroleum hydrocarbons at this site, which was deemed a reference site, suggesting the possibility of exposure to the natural seepages in the area. In November 2011, four locations in the vicinity of Heywood Shoal were discretely sampled to identify if these biomarkers of exposure were still high two years following the incident.

Male red emperor exhibited a significant liver detoxification activity at one of the Heywood Shoal sites, suggesting recent exposure to hydrocarbons.

Red emperor collected at the three other sites close to Heywood Shoal, as well as all collected goldband snapper, had liver detoxification activity similar to those fish originating from the reference site. Elevated induction of liver detoxification activity in male red emperor collected in the area of Heywood Shoal is consistent with past observations made at this site.

A vacuutainer and needle were used to collect blood from the caudal vein in sampled fish

It is possible the presence of the Montara rig attracts fish including red emperor prey resulting in more abundant food than those living away from such structures.

It seems reasonable to hypothesise that food abundance might be responsible for the differing condition factors found in species between control and hydrocarbon impacted sites in November 2010.

Sampling which occurred in November 2011 found the condition factor of goldband snapper collected at three of the four sites closest to the rig was similar to the condition factors in fish originating from the reference sites.

Moreover, the condition factor of red emperors collected at all sites close to the rig did not differ from the condition factors in red emperors from the reference site. It was, therefore, concluded fish of both species collected at the four sites close to Montara two years after the incident are in good physical conditions.

Liver Somatic Index

Liver Somatic Index is the ratio of the liver size relative to body size. It provides an index widely used as a general indicator of chronic exposure to contaminants.

A larger liver can be the result of exposure to contaminants, particularly contaminants which are metabolised by the liver. However, under field conditions, LSI can also vary according to biological, chemical and/or physical factors other than pollutants, such as onset of reproductive activity.

Higher liver size relative to body size was observed for both species of fish in numerous samplings across a number of sites.

While the observation is consistent through time and species, it is unlikely larger liver sizes are due to continuing exposure to contamination, as other biomarkers specific to petroleum hydrocarbons did not confirm recent exposure of fish to these compounds at these same locations. It is also unlikely enlarged livers are related to reproductive activities, as the reproductive status of fish from all sites was similar.

Enlarged livers in fish collected close to the rig might be related to nutritional status of the fish.

For both species of fish, LSI has shown altered values in post-spill samplings. The liver is a plastic organ with the capability to adjust its mass when sustained metabolic demand occurs. This biological response of altering hepatic tissue mass might take several months.

While in the final phase of the study, short-term biomarkers of exposure suggest no recent exposure to petroleum hydrocarbons, so it is possible the liver size has not fully returned to pre-spill conditions in fish collected close to the well head. Alternatively, the lower liver size in fish collected within 50 kilometres of the rig might be related to environmental conditions in the vicinity of Montara, including prey abundance. Abundance of prey might not have returned to pre-spill event levels, resulting in lower energy reserves stored in the liver of goldband snapper and red emperor.

Gonado-somatic Index

GSI is the ratio of the gonad weight to the total body weight. It is expected a large fish will produce many eggs and a smaller fish will, proportionally, produce fewer eggs.

While some differences in GSI were noted in the first three phases of the study, these were not statistically significant overall. The hydrocarbons from Montara could have been one cause in these reproductive effort variations, but they could also have been the result of differences in breeding status in the different populations. The differences require further investigation to determine their cause.

Two years following the end of the incident, the GSI appeared to vary considerably between sites, especially for female goldband snapper. Differences between sites can be explained by the fact that at most sites some female fish had well developed mature gonads ready to spawn, while other female fish were at earlier phases of gonadal development.

The trend observed in site monitoring was low GSIs were initially observed in fish collected close to the well head, but there was a temporal trend towards similar GSIs to the reference fish taken from the reference sites.

Gonad examination

Histological examination of the gonads provides important information on the reproductive state of the fish as a result of potential exposure to the contaminants.

For both species of fish, histological examination of the cells involved in the reproductive process, the male spermatocytes and female oocytes revealed no inter-site differences. Male gonads of each individual contained spermatagonia, which are intermediaries in the production of sperm, at a range of developmental stages. The majority of spermatagonia samples contained fully developed sperm. These fish appeared to be either spawning or about to spawn.

Liver detoxification enzymes

Liver detoxification enzymes are part of a detoxification system found in most vertebrates. Upon exposure to certain classes of contaminants such as petroleum hydrocarbons, liver enzymes are induced at high levels to oxidise xenobiotics and to eliminate the metabolite out of the body.

Specific detoxification enzymes are measurable in fish livers even if the inducing chemical is well below detectable levels in the environment (Landis and Yu, 1995).

Liver detoxification enzymes are normally present with relatively low activity in animals as they also fulfil several metabolic functions. In fact, activity of the liver enzymes can vary naturally with sexual hormones, increasing the variability of this biomarker. Because of this potential alteration, liver detoxification activity has to be considered separately for male and female individuals.

Initial investigations carried out following the Montara oil spill revealed goldband snapper and red emperor collected in close proximity to the Montara rig exhibited elevated liver enzyme activity. This suggested these fish were exposed to, and had assimilated, environmental contaminants and were in the process of metabolising these environmental contaminants.

Sampling which occurred in November 2011, two years following the end of the oil spill, found liver detoxification activity in both species of fish, and in both sexes, were similar in fish collected close to Montara compared to fish collected in reference areas distant to Montara. This result suggests fish collected in close proximity to Montara were no longer exposed to the inducing compound which triggered elevated liver enzyme activity levels in past studies.

Similar conclusions were reached when a fish health monitoring study was conducted following the 2002 Prestige oil spill which occurred off the coast of Spain, with liver detoxification levels having returned to reference levels within a three-year period.

Biliary metabolites

PAH biliary metabolites are the metabolised products of polycyclic aromatic hydrocarbons, which accumulate in the biliary secretions.

Following metabolism of a chemical, like PAHs, by the liver detoxification enzymes, the metabolites are directed to the biliary secretions for elimination out of the body via the intestine. The liquid bile secretions can therefore accumulate metabolites at levels up to 1,000 times higher than in the surrounding environment (Hellou and Payne 1987; Meador, et al. 1995), making this biomarker a very sensitive indicator of exposure to petroleum hydrocarbons.

Fish, like most vertebrates, do not accumulate petroleum hydrocarbons, including PAHs, in their flesh because they are capable of metabolising them at rates which prevent significant bioaccumulation (Hartung, 1995). Enzymes responsible for the metabolisation of PAHs do not appear to be affected by the sex or by reproductive activity of the animal. Consequently, biliary metabolite levels can be combined for both male and female fish of the same species.

In the earlier sampling, both species of fish collected in proximity of Montara, on at least one occasion, showed elevated PAH biliary metabolite levels relative to reference fish.

In the final phase of the study, however, goldband snapper and red emperor collected at sites within 50 kilometres from the well head no longer exhibited elevated PAH biliary metabolite levels relative to reference fish.

This result, along with the low liver detoxification activity, supports the hypothesis that fish were no longer exposed to petroleum hydrocarbons from Montara approximately 27 months after the spill event began.

Rare fish hermaphrodite examined

In the first reported case of its kind in goldband snapper, an interesting case of fish hermaphroditism, or the presence of a male and a female tissue in the same gonad, was observed in this study.

The testes of this single goldband snapper from one site contained ovarian tissue. The testicular tissue was interspersed with immature female reproductive oocytes. While such an occurrence can be due to a contamination event (e.g. Jobling, et al. 1998), there is no evidence to suggest such a link in this case.

The occurrence of hermaphroditism is well documented in some fish families. Many species of Serranid are protogynous hermaphrodites, starting life as females before becoming males. Species of Sparidae display a range of reproductive styles including protogyny, protandry and rudimentary hermaphroditism, or having both male and female gonadal tissue in early life stages.

The occurrence of intersex gonads, that is the presence of a female reproductive cell in a testis, has also been reported as naturally occurring (e.g., Korner, et al. 2005). However, in the Lutjanidae (the family to which goldband snapper belongs) none of these has been reported, making this observation remarkable.

Sorbitol dehydrogenase activity

The enzyme sorbitol dehydrogenase (SDH) is primarily found in the liver. Its involvement in energy metabolism is biologically relevant for metabolic purposes. In addition, the presence of SDH in the bloodstream indicates liver damage which might follow exposure to contamination (Heath 1995).

Previous work has shown such increases in SDH in the bloodstream can follow exposure to organic contaminants including petrogenic compounds like PAHs (Ozetric and Krajnovic-Ozetric, 1993). SDH activity is not affected by the sex of the animals or their reproductive status.

Fish, like most vertebrates, do not accumulate petroleum hydrocarbons in their flesh because they are capable of metabolising them at rates which prevent significant bioaccumulation.

In earlier investigations on the effects of the Montara spill on fish health, levels of SDH activity in the bloodstream of goldband snapper were at similar levels in exposed snapper and reference fish.

However, immediately following the Montara oil spill, red emperor collected in impacted areas during in Phase 1 (November 2009) showed a significant increase in SDH activity in the blood serum, suggesting liver cell damage potentially related to petroleum hydrocarbon exposure. The elevated SDH levels in red emperor were not observed in subsequent sampling events, indicating liver function in fish collected in impacted areas had returned to reference levels within four months following the end of the oil spill.

Sampling which occurred in November 2011 found sorbitol dehydrogenase activity in goldband snapper and red emperor remained comparable in fish collected from sites close to Montara, as well as in fish collected from the reference areas distant from the rig. This result indicates the Montara spill has not resulted in chronic liver damage in fish collected within 148 kilometres from where the hydrocarbon release occurred.

Oxidative DNA damage

Oxidative DNA damage is a naturally occurring event related to physiological processes and normal metabolism in animals. However, exposure to certain factors such as sunlight or PAHs can significantly increase the amount of oxidative DNA damage experienced by an organism. Importantly, this form of DNA damage is not mutagenic or carcinogenic.

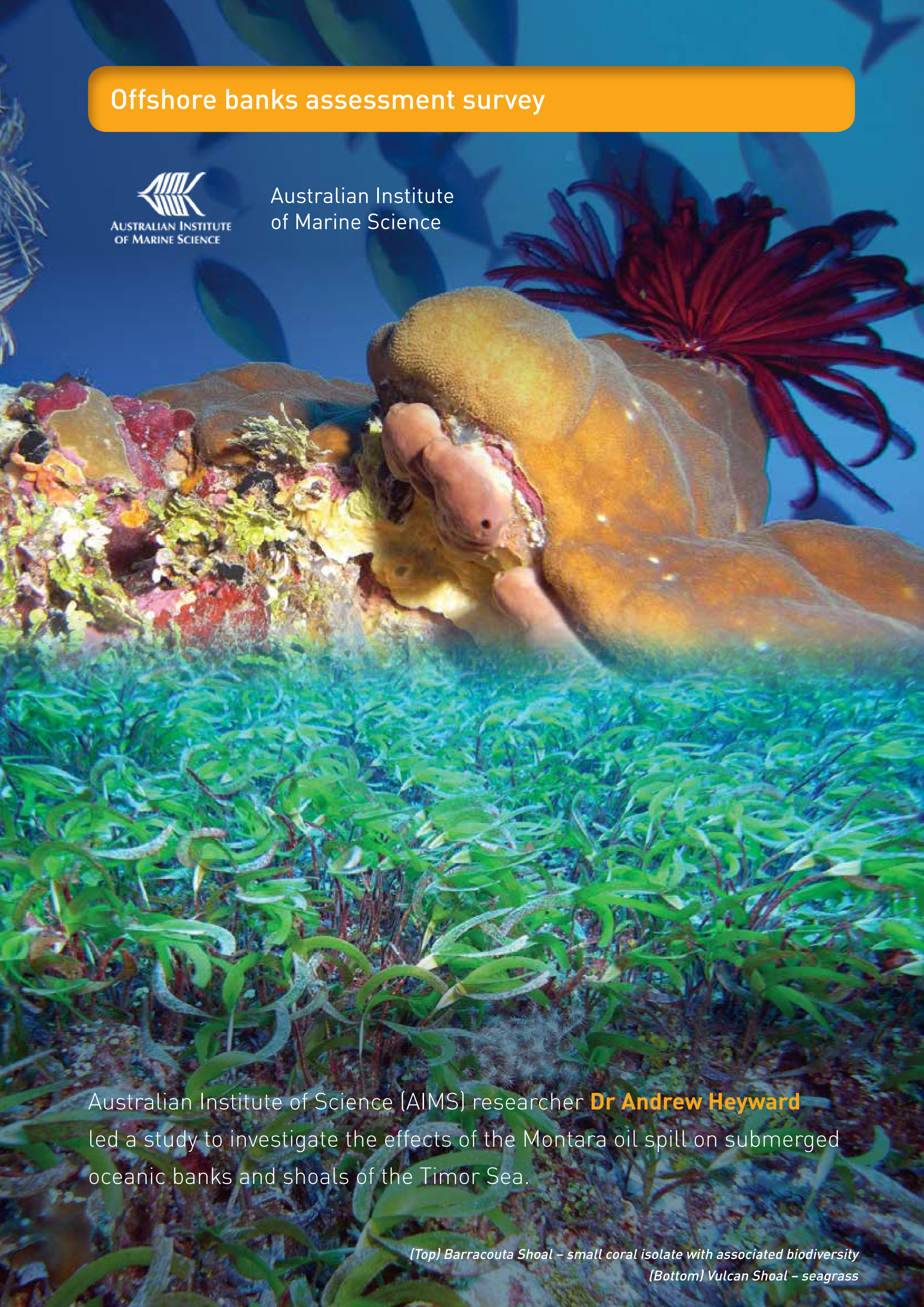
Four months following the end of the incident, red emperors captured closer to the rig had significantly higher levels of oxidative DNA damage than those captured in the reference zone. This is an indication of a physiological difference in either the rate of damage and endogenous, or natural internal repair, which occurs in these fish. It is not a difference in their susceptibility to increased oxidative damage.

There were no differences in the levels of oxidative damage in goldband snapper between the study sites.

Statistically, there were overall differences between the oxidative DNA damage in red emperor at the study sites. However, there were no consistent trends in these differences which were associated with the location Montara. Importantly, none of the red emperor from sites closest to Montara had oxidative DNA damage levels which were above those measured in fish from the reference location.

This discussion was based on the S4A Assessment of effects on Timor Sea fish research study, but was enhanced by extensive discussions with Curtin University's Associate Professor Marthe Monique Gagnon and Dr Christopher Rawson. PTTEP AA is grateful to Associate Professor Gagnon, Dr Rawson and Curtin University for their contributions to this report.

All images in this discussion are owned and supplied courtesy of Curtin University.



Offshore banks assessment survey

Australian Institute of Marine Science

Australian Institute of Science (AIMS) researcher **Dr Andrew Heyward** led a study to investigate the effects of the Montara oil spill on submerged oceanic banks and shoals of the Timor Sea.

(Top) Barracouta Shoal – small coral isolate with associated biodiversity
(Bottom) Vulcan Shoal – seagrass

OVERVIEW

The objectives of the banks and shoals study were to:

- identify and quantify their physical character (depth, substrate)
- identify their associated biota and community structure
- estimate their potential exposure to surface oil and dispersed oil
- identify any obvious damage to their associated communities.

The north west oceanic banks and shoals are abrupt geological features that rise to within 15-50 metres from the sea surface. Initially they rise steeply from depths of 100-200 metres on the continental shelf and begin to flatten out into a plateau at around 40-50 metres depth.

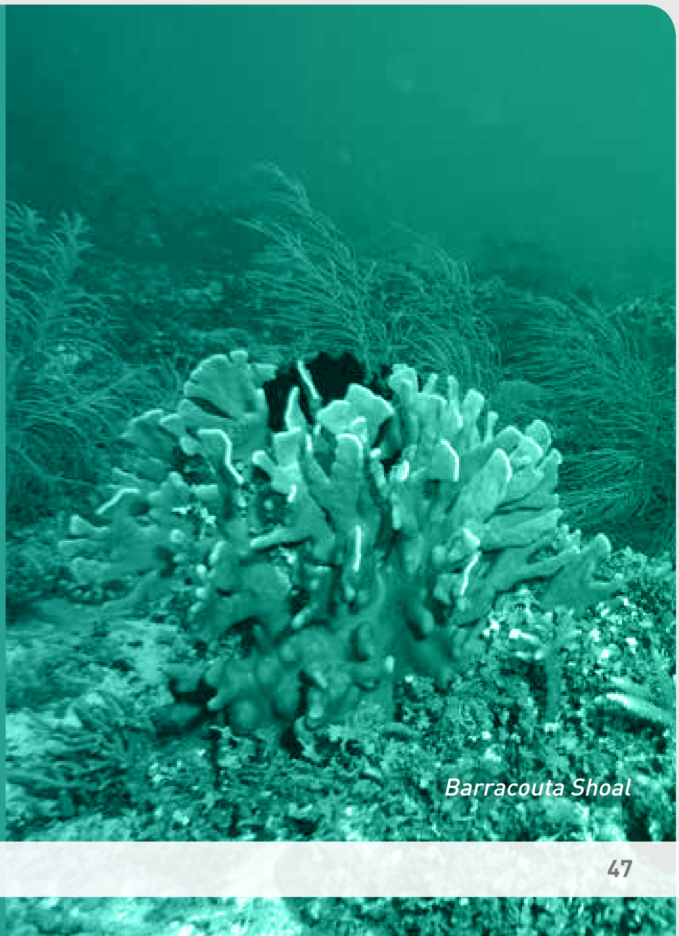
The shoal plateaus have been found to support diverse coral reef ecosystems with relatively clear oceanic waters providing adequate light for photosynthetic organisms, including hard corals, macroalgae and seagrass. Nautical charts reveal 163 of these geological features within 200 kilometres of Montara. Therefore, these features are key ecological communities in the region which are likely to play an important role in maintaining biological diversity and connectivity across Australia's North West Shelf.

While potentially high biological diversity had previously been noted for the banks and shoals, there was no pre-existing baseline data. Therefore, the effects of the spill were assessed using a gradient analysis.

Initially, in April 2010, two shoals close to Montara were surveyed including Vulcan Shoal (27 kilometres south west) and Barracouta Shoal (55 kilometres west). This survey was followed by a larger study in March and April 2011 which included the two original shoals, with an additional seven located up to 150 kilometres from Montara. These nine sites were spread across three regions selected to represent a gradient of high, medium and low exposure to the oil spill.

Surveys were undertaken to identify the physical and biological character of the top of the banks and shoals to a depth of 60 metres. Measurements included sediment hydrocarbon levels, benthic habitat and fish community composition. High resolution bathymetry, undertaken up to approximately 200 metres in some cases, was collected to provide detailed information on the depth, structure and topography of the shoals. The research had a very high discovery component with little detailed scientific analysis of these regions having being undertaken previously.

The research in this study had a high discovery component since shoals in the Timor Sea had never before been subject to such a detailed scientific analysis.



Barracouta Shoal

KEY RESEARCH FINDINGS

Research investigating the effect of the oil spill determined:

- there were no obvious signs of recent disturbance on two shoals (Barracouta and Vulcan Shoals) close to Montara six months after the oil spill had ceased. However, 16 months after the release ceased there was a very significant but unexplained loss of the extensive seagrass meadows originally present on Vulcan Shoal
- there was a widespread, low-level presence of degraded oil and, at some sites, nearly double the concentration of oil residues were found compared with measurements taken before the uncontrolled release (e.g. adjacent to Eugene McDermott and Montara). Where detected, oil residues were found to be severely degraded and at concentrations several orders of magnitude lower than the levels at which biological effects are expected. The degraded nature of the hydrocarbons prevented source matching or assessment of potential extent. This may have been influenced by the time which had passed before the undertaking of the study following the Montara oil spill
- analyses of the fish assemblage and benthic community data found a weak or negligible effect of the uncontrolled release with natural processes, including depth and aspect, found to be the main predictors of the patterns observed
- some of the results suggested a decrease in diversity and total abundance of fish species, along with increases in mean size of fishes at those shoals closest (within 50 kilometres) to Montara. While these results did not exclude a potential effect of exposure to hydrocarbons and dispersants on the fish communities, and the impacts of the uncontrolled release can not be discounted, the observed variations between shoals again appeared to be dominated by natural processes.

2010 survey

The first survey in April 2010 was a preliminary study of two shoals close to the well head (Barracouta and Vulcan Shoals). This first survey was conducted six months after the uncontrolled release had been stopped. These shoals were surveyed to understand the possible scale of the impact and to determine the variability of community composition within, and between, these two adjacent shoals.

The initial survey found:

- both shoals supported highly diverse ecosystems with communities typically seen on many coral reefs
- pronounced differences within, and especially between, the two shoals in the relative abundance of dominant groups
- no obvious signs of a major, recent disturbance.

However, this study was not designed to detect any smaller or more localised impacts, nor could it determine if any other shoals in the region have been impacted from the oil release at Montara. The cause of the pronounced variability observed between Barracouta and Vulcan Shoals is unknown, but could be related to disturbance events such as hurricanes, bathymetry, or to the biology of the dominant organisms, such as founder events, clonal reproduction or larval dispersal.

Founder effects occur when an area is colonised by just a few successful individuals of a species after a disturbance. Rapid growth, often through clonal reproduction, can lead to these organisms dominating a benthic marine community. Founder events may explain the very extensive field of soft coral *Nephthea* sp. which covered a significant proportion of the western margin of Barracouta Shoal. In contrast, Vulcan Shoal supported an extensive and lush field of the seagrass, *Thallasodendron ciliatum*, which was not seen on Barracouta.

2011 survey

The second survey, conducted in March and April 2011, extended the research to provide a more comprehensive survey of the effect of the oil spill on the banks and shoals of the Timor Sea.

> *Median fish abundance and fish species richness on the shoals were between 1.25 to three times higher than for equivalent banks, shoals and reef edges in the Great Barrier Reef Marine Park.*

The survey examined nine shoals spread across three regions selected to represent high, medium and low exposure to released oil and gas. This included revisiting Vulcan and Barracouta Shoals. In addition to measuring sediment hydrocarbon contamination, shoal depth, topography and benthic habitat, the second survey included a comprehensive assessment of the fish assemblage.

The 2011 research found:

- a widespread, low-level presence of degraded oil and the presence of concentrations at some sites, which were nearly double levels measured before the oil spill. This presence was several orders of magnitude lower than the levels at which biological effects are expected. Spatial patterns of hydrocarbons were consistent with hydrocarbons originating from the Montara reservoir. However, source matching could not be achieved because of the extensive weathering of the oil
- a multivariate analysis of the community structure recognised six assemblages of fishes among the shoals, principally determined by depth, the amount of reefal substrate and the size (area) of the shoal plateau
- species level identifications found the fish fauna to be more diverse than seen on equivalent seabed features of the Great Barrier Reef
- the submerged shoals supported many of the same species in common with the emergent coral reefs of the region (such as Ashmore and Cartier Reefs and the Scott Reef complex). They may, therefore, act as stepping stones for enhanced biological connectivity among the reef systems of Australia's north west.

> *Both benthic communities and fish faunas of the shoals were diverse and varied within and between shoals. The biota on these shoals was typical of known shallow tropical reef systems.*

While potentially high biological diversity had previously been noted for the oceanic banks and shoals of the Timor Sea (Heyward, et al. 1997), the lack of detailed pre-existing baseline data severely constrained monitoring of the spill.

However, detailed data captured for the nine shoals from this study provides an important baseline characterising these unique and diverse marine communities.
This research is invaluable in terms of providing a foundation from which communities can be tracked, change and understood over time. It will be especially valuable for any post-impact studies if there are any future environmental incidents in the region.

Barracouta Shoal

DISCUSSION

Montara is within the North West Shelf marine biogeographic ecosystem province. Within the province there are both submerged and emergent reefs and cays along the outer edge of the continental shelf, extending from the Lydoch and Troubadour Shoals in the Arafura Sea (north of Darwin) to the Rowley Shoals north west of Broome.

The shoals sampled in this study were highly diverse systems set within complex oceanography. The seabed on the flat, plateau-like areas of the shoal tops were found to be dominated by benthic primary producers, including algae and hard corals, interspersed with sand and rubble patches. Both benthic communities and fish faunas of the shoals were diverse and varied within and between shoals. The biota on these shoals was typical of known shallow tropical reef systems.

The benthic biota recorded included many coral and algal species and are likely to mirror regional coral reef diversity.

An analysis of the fish community structure recognised six assemblages of fishes among the shoals, with the shoals principally characterised by their:

- depth
- the amount of reef substrata
- plateau size (area).

The shoal habitats provide an additional regional reservoir of megafauna species, such as sharks and sea snakes, typically associated with the emergent reefs.

In the absence of a baseline for the region, it is not possible to state that there has been no oil spill impact on the fish and benthic communities. It is also difficult to establish if the spill has been the cause of any of the observed patterns. This is especially the case for the fish assemblage data, which were derived from a single survey, providing only a snapshot sample of the status of fish on the shoals.

Sediments

Due to the degraded nature of the oil found in sediments through this research, it was not possible to match the oil found in the sediments to the Montara reservoir. Previous studies in the area (Burns, et al. 2001, 2010) have shown there is a background presence of petroleum hydrocarbons which could originate from the oil industry, passing ships, discharge from fishing boats and from natural oil seeps.

Since source matching was not possible, the origin of the oil in the sediment remains undetermined.

Given the time which had elapsed between the oil spill and the commissioning of the study, and given the associated problems with source matching, it is unlikely the true spatial extent of any possible sediment contamination from the spill will ever be categorically known.

Seagrass at Vulcan Shoal

At Vulcan Shoal, located closest to Montara (27 kilometres south west), a very significant loss of seagrass was apparent in 2011 when compared with data the 2010 survey. The causes of this loss, which occurred in the interim period between the two field surveys 6-16 months after the spill ceased, cannot be reliably determined.

Sediment samples confirm Vulcan Shoal had hydrocarbons present and this exposure, while low, was higher than other shoals in this study. The sensitivity of some seagrass species to hydrocarbons has been reported in the general literature with this sensitivity found to be greater in the presence of dispersants. However, as the first survey found the seagrass in excellent apparent health, a highly delayed effect from the oil spill resulting in a change sometime between 6-16 months afterward seems unlikely.

Only extensive remnant rhizomes remained in 2011, although there was evidence of a few new leaf shoots developing. In contrast, the hard corals on Vulcan Shoal were normal in appearance and had not decreased in abundance during the same period. This suggested the cause of the seagrass loss was either selective to seagrass or perhaps a physical disturbance only affecting loosely attached biota.

An analysis of images from the same locations between the two years tends to support the hypothesis of a physical scouring event, as the abundance of *Halimeda* algae and Didemnid ascidians in the same areas were also markedly reduced. Therefore, a storm or another source of strong seabed disturbance (i.e. cyclone) may have been responsible.

Barracouta Shoal filter feeder mixed habitat

However, with no record of a cyclone directly disturbing Vulcan Shoal during the time period in question a variety of other agents of rapid change in seagrass communities were considered. One possibility was predation by an outbreak in the local population of urchins or thermal stress due to abnormal sea water temperature. Analysis of 2010 and 2011 data for urchins found no evidence for large populations on Vulcan Shoal, bearing in mind images were mostly collected during daylight, with urchins most active at night.

Analysis of blended satellite sea surface temperature data does reveal a rapid change from unusually warm conditions in 2010 to unusually cool conditions in 2011. Therefore, an effect of seawater temperature cannot be excluded.

Bioregional context and existing information on shoals

A collation of industry survey data from shoals in the central part of the North West Shelf marine biogeographic province undertaken in the mid-1990s (Heyward, et al. 1997) noted the abrupt bathymetry of the shoals and found high diversity ecosystems could be found there. A number of shared biological features and habitat types were reported, but marked differences between individual shoals were also found.

The offshore waters in this region tend to be clear, enabling some photosynthetic species – organisms such as algae and corals which capture light to acquire energy – to thrive even at depths of 50 metres or more in places. As many submerged shoals may rise to within 15-50 metres of the sea surface, shallower habitats exposed to adequate sunlight have at least the potential to support a diverse floral and faunal composition similar to the emergent oceanic reef systems. However, due to the remoteness of the region most of the banks and shoals had been either unstudied or poorly characterised.

Based on general observations in this region, benthic primary producers such as algae and reef-building corals can be dominant to depths of at least 50-60 metres. Preliminary analysis of the bathymetry around Montara identified more than 20 possible shoal features within 100 kilometres distance and greater than 100 similar bathymetric features within 200 kilometres. Each of these have the potential to support diverse tropical ecosystems and, where the depths are shallow enough to support phototrophic organisms, may support coral reef primary producers and associated biodiversity.

The offshore waters in this region tend to be clear, enabling some photosynthetic species – organisms such as algae and corals which capture light to acquire energy – to thrive even at depths of 50 metres.

Benthic community

Gradient analysis undertaken of shoal and reef slopes showed no particular spatial pattern in the abundance and diversity for major benthic groups in relation to exposure to the oil spill. Three hydrocarbon exposure variables were used in the analysis:

1. hours of exposure to the modeled Montara plume
2. distance from Montara spill
3. hydrocarbon concentrations in sediments.

This allowed a relative ranking of any potential effect of the Montara oil spill, noting sediment hydrocarbon levels do not necessarily relate to Montara, given other potential sources in the region. However, none of the three variables explained significant variability in benthic composition. Ascidians and pocilloporid corals were the only two benthic species with an exposure variable included in the best analysis model. This model, however, was not significantly different from another where the hydrocarbon exposure variable was excluded. Nonetheless, a change in the relative ranking of the results when analysis were run using finer taxonomic groups suggest any effect is more likely to be operating on small taxonomic groups or individual species rather than the whole benthos.

In corals, for example, across taxa there is evidence for different sensitivities to thermal stress which results in bleaching. In addition, the response of individual species and genera may be influenced by past disturbance history (Guest, et al. 2012). At the overall community level, the interactions are likely to swamp any such effect if a minority of species in a particular functional group demonstrates a response.

There was a clear correlation between depth and live coral cover, with the most diverse and abundant coral found typically on the shallowest areas of each shoal. The coral assemblages varied between shoals, but were broadly grouped into shallower shoals, with corals in the families Acroporidae and Poritidae dominant. Deeper shoal margins, however, particularly at Heywood Shoal and the two deepest shoals, Wave Governor Bank and Shoal 25, were strongly characterised by an abundance of various mushroom coral species in the family Fungiidae.

The range of live hard coral cover would be regarded as low to moderate for transects placed on a shallow reef in a potentially coral-dominated habitat. However, as these shoal surveys integrated data across the entire shoal plateau, the live coral cover present may be comparable to, or higher than, that found on some shallow reefs, if the sampling were to include lagoonal sandy habitats. Consequently, the coral cover on the shoals seems notable and was high within particular habitats.

There was no obvious sign of widespread stress, such as bleached or recently dead corals, but without baseline data from before the oil spill, temporal changes remain unknown. The two shoals, Vulcan and Barracouta, surveyed in both 2010 and 2011, provided evidence of a major change in the benthic community at Vulcan, yet little inter-annual change at Barracouta.

The shoals may act as stepping stones for enhanced biological connectivity throughout both the submerged and emergent reef systems of Australia's north west.

Barracouta Shoal

Fish communities

The uncontrolled release of hydrocarbons into the sea, along with dispersant chemicals used in operational response to spills, has the potential to effect fish communities in a number of ways. This includes the reduced survival of eggs and larvae exposed to hydrocarbons (Carles, et al. 1999; Carles, et al. 2000; Incardona, et al. 2012), and dispersants (Couillard, et al. 2005), and reduced survival and growth of recruits and adults, with subsequent population level effects (Heintz, et al. 2000).

Assessment of the potential impacts on the fish communities following the oil spill, where both hydrocarbons and dispersants were released into the sea, included surveys of fish diversity, abundance and size across the nine submerged banks and shoals.

To identify what was driving patterns observed in the fish assemblage data, analyses examined the relative influence of environmental variables known to be important in structuring fish populations (including depth, aspect and topographic complexity) and variables describing exposure to the spill (including distance from Montara, hydrocarbons in sediments and maximum hours of oil exposure).

As there was no pre-existing baseline information on shoal-associated fish communities for this area, contrasts were made between banks and shoals of predicted high, medium and low exposure to the spill. Such an assessment is complicated by the fact that fish communities vary with habitat at a range of spatial scales (e.g. Friedlander and Parrish 1998; Kaiser, et al. 1998). Therefore, the cross-shelf location, size, and varying habitats of the banks and shoals meant the influence of such natural variation on the fish communities needed to be considered in any assessment of potential hydrocarbon or dispersant effects.

Results from these analyses found fish diversity and richness was most highly influenced by natural processes, particularly depth and aspect, with rugosity variables having some influence at a more localised scale. Higher species richness was typically associated with the shallowest areas of the shoal plateau. This was also often an area of consolidated complex habitat, where corals were common. Fish abundance tended to mirror species richness, but the association with the shallow, species-rich areas was variable among shoals. In addition, there was a consistent region of high abundance of fishes around shoal edges.

The study concluded there were weak or negligible effects of oil exposure on the structure of fish assemblages with natural processes, particularly depth and aspect, found to be the main predictors of the patterns observed. Two approaches were taken to analyse the fish assemblage data.

The first approach found all indices of oil exposure to be weak or negligible in predicting species richness, total abundance, community structure and occurrence of individual, common species.

The fish communities were significantly related to habitat, although the strength of these relationships varied. The pattern between species richness and habitat was reasonably strong while the habitat relationships for total abundance, size and biomass were more variable, albeit still significant.

The second approach found, however, that while the majority of the variation in species richness, abundance, size and biomass was attributed to habitat variables (calcareous reef and depth the most important), there were subtle but significant trends in community structure in relation to the exposure metrics. This approach found:

- a marginally significant result for species richness, with richness declining with decreasing distance to Montara and increasing hours of exposure
- there was some evidence total abundance decreased with increasing concentration of hydrocarbons in the sediments and decreasing distance to Montara
- a very small effect of hours of exposure was detected for mean fish length (less than a 0.2% change in length). Mean length of fish increased with increasing hydrocarbon concentration and increases in the minimum number of hours of exposure, suggesting that smaller fish declined in abundance with increasing exposure
- a small and marginally significant effect of distance to Montara was detected for fish biomass.

Why would a decrease in species richness and abundance, and an increase in mean size, be consistent with exposure to hydrocarbons and dispersants? Theoretically, sensitivity to hydrocarbons and dispersants is a function of the following:

- timing of exposure – significant impact can be expected during spawning or recruitment periods when eggs, larvae and new recruits are vulnerable to exposure
- duration of exposure – greater lengths of exposure may increase impacts
- mobility – species with low mobility are unable to avoid the spill may be affected more than species with avoidance capabilities (Volgelbein and Under 2006)
- feeding modes – species that increase their exposure, such as species in significant contact with the contaminated sediments (Kennicutt, et al. 1991), or preying on contaminated zooplankton (Teale and Howarth 1984), may be more sensitive
- body size – given the impacts of hydrocarbon exposure on gills, skin and liver (Giari, et al. 2012; Cohen, et al. 2001), smaller species and smaller individuals within species are more vulnerable to exposure because they have a higher surface area to volume relationship, they have higher gill surface area per unit body weight (Pauly 1998) and respire more quickly (Peters 1986).

Thus, species richness might be expected to decline with exposure to hydrocarbons where some species are relatively sensitive to hydrocarbons and/or dispersants due to low mobility, vulnerable feeding modes or small size, compounded by exposure at reproductively sensitive periods.

While some potential effects of the oil exposure indices on the structure of fish assemblages were detected, these must be interpreted with caution. Currently, very little is known about oceanic influences on fish community structure at the offshore edge of the shelf and these may well be present in the study area.

The shoals closest to the uncontrolled release had mean depths comparable to, or shallower, than other shoals, so depth alone cannot be invoked as an explanation for the increase in fish length in relation to increasing hydrocarbon concentrations.

Further north, tidally-trapped internal waves, episodic upwelling and the 'Indonesian Throughflow' occurring at the outer edge of the shelf could be expected to produce cross-shelf gradients in environmental conditions for fishes. Thus, the cross-shelf position of a shoal cannot be disregarded as a factor potentially confounding any signals of the oil spill in fish assemblages. Better knowledge of local oceanographic processes surrounding the shoals could improve the predictive capability of models of fish community structure.

Consequently, while the shoals support abundant and diverse fish communities, predominantly influenced by the natural attributes of each location, without pre-spill baselines we cannot exclude influence from the spill in contributing to the subtle spatial patterns observed. Independent surveys have reported a hydrocarbon biomarker signal in at least four larger fish species in the region which attenuates with distance from Montara, (Gagnon and Rawson, 2011), demonstrating at least some level of hydrocarbon interaction with both demersal and pelagic species.

Vulcan Shoal – seagrass

CONCLUSION

While the oceanic banks and shoals were found to support diverse and abundant fish communities predominantly influenced by the natural attributes of each location, without pre-spill baselines we cannot exclude influence from the spill in contributing to the subtle spatial patterns observed. The data captured from the nine shoals used here in the Montara study provide a foundation for excellent scientific study baselines.

However, robust baselines also need to include data on natural temporal and spatial variability. Studies of the emergent coral reefs in this region have shown natural variability can be very significant at decadal time scales (e.g. Smith, et al. 2008).

Long-term monitoring is needed at the shoals to better understand the status of the biological communities and how this changes with time. Of particular importance is examining the possible causes, and any future recovery, of the seagrass meadows at Vulcan Shoal.

This discussion was based on the S5 Offshore banks assessment survey research study (led by Dr Andrew Heyward and co-authored by a number of AIMS colleagues). PTTEP AA is grateful to AIMS and its employees for their contributions to this report.

All images in this discussion supplied courtesy of AIMS.

Shoreline ecological ground surveys (corals)

Australian Institute of Marine Science

Australian Institute of Marine Science (AIMS) researcher **Dr Andrew Heyward** led a study to identify the possible effects of the Montara oil spill on coral and fish health at the Ashmore, Cartier and Seringapatam Reefs, all of which are located on the North West Shelf marine biogeographic province in the Timor Sea.

Barracouta Shoal

OVERVIEW

Surveys of shallow reef benthic habitats took place in April 2010 and February to March 2011. Ashmore Reef and Cartier Islet, 167 kilometres north west and 108 kilometres north west from Montara respectively, were the principal emergent reefs of interest, as they were the two closest to Montara.

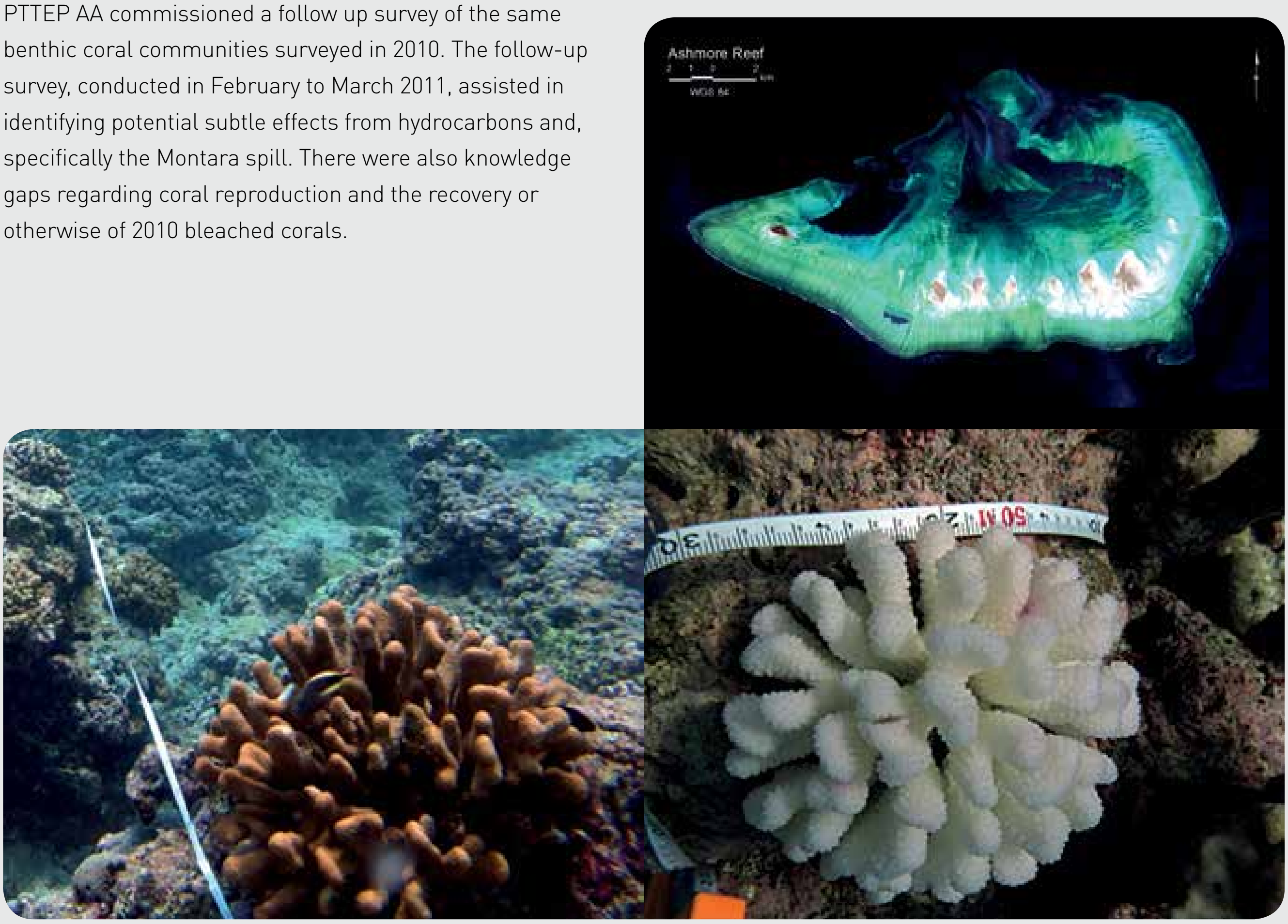
To provide a control location, the same sampling was conducted at Seringapatam Reef, 296 kilometres south east from Montara and far from modelled oil trajectories, a similar emergent reef in the same bioregion.

Within the North West Shelf marine biogeographic province there are both submerged and emergent reefs and banks along the outer edge of the continental shelf, extending from the Lydoch and Troubadour Shoals in the Arafura Sea north of Darwin to the Rowley Shoals north west of Broome. This 246,404 kilometre^2 area is also referred to as the Oceanic Shoals meso-scale region within the Integrated Marine and Coastal Regionalisation of Australia classification.

PTTEP AA commissioned a follow up survey of the same benthic coral communities surveyed in 2010. The follow-up survey, conducted in February to March 2011, assisted in identifying potential subtle effects from hydrocarbons and, specifically the Montara spill. There were also knowledge gaps regarding coral reproduction and the recovery or otherwise of 2010 bleached corals.

Overall, the study investigated the ongoing state of reef communities as well as examining other aspects of reef health, including coral reproduction and fish community diversity.

In the 2011 survey, an extended and more diverse selection of sampling was undertaken to see if processes of ongoing coral population renewal via sexual reproduction and recruitment was occurring. Recruitment in this context refers to juvenile corals floating in the water column which, after a period of time, settle down on the reef (i.e. recruit to the reef) . The 2011 latter survey also included a comprehensive assessment of the fish communities associated with the benthic sites, as well as a re-sampling of reef sediments to follow up on the status of low levels of hydrocarbon detections noted in the 2010 report.



(Clockwise from top right) Ashmore Reef; bleached Pocillopora edouxi, *a common site during the 2010 surveys; the same* Pocillopora edouxi *species in 2011, appearing to be healthy*

KEY RESEARCH FINDINGS

The composition and abundance of the major benthic biological group – such as corals, filter feeders, ascidians, fish etc – measured in April 2010 provided no evidence of recent major disturbance at any of the reefs, suggesting any effects of oil reaching these reefs were minor, transitory or sub-lethal and not detectable with the sampling methods used.

There was no evidence of a broad disturbance which correlated with impacts from the Montara spill. There were no obvious patterns identified in the fish community surveys, which included no impact on the recruitment of reef fishes. Nor was there evidence of missing or truncated size classes in size-frequency distributions.

The condition of the coral communities at Ashmore and Cartier Reefs in the 2010 survey was consistent with surveys conducted before the uncontrolled release. Although there was no evidence of a recent major disturbance that could be attributable to any uncontrolled release, there was evidence of a recent coral bleaching event. This was most likely caused by elevated water temperatures (Heyward, et al. 2010).

While there was no visual sign of oil or waxy oil on the sea surface around the reefs, or during shoreline walks on sandy islets at each reef, laboratory analysis of sediment samples detected some hydrocarbons at multiple sites at all three reefs.

There were seven samples with higher hydrocarbon levels, in the range of 0.2-0.58 μg/g (or parts per million) and there was some indication they had a similar oil composition to the Montara field reference sample. The higher level sample from Seringapatam did not have the same chemical pattern, hence was not Montara crude oil.

Oil was observed at Ashmore Reef during the oil spill. Given the higher presence of hydrocarbons there, compared with the more distantly located Seringapatam Reef, the pattern is consistent with contamination from the spill. However, given the degraded state of the oil, it was not possible to accurately identify the hydrocarbon components and hence to unequivocally link the hydrocarbons at Ashmore Reef to the Montara spill.

Previous studies in the Timor Sea and North West Shelf have shown there is a background presence of petroleum hydrocarbons (Burns, et al. 2001, 2010). These could originate from natural seeps, the oil industry, passing ships or discharge from fishing boats.

While there was no visual sign of oil or waxy oil on the sea surface around the reefs, or during shoreline walks on sandy islets at each reef, laboratory analysis of sediment samples detected some hydrocarbons at multiple sites at all three reefs.

Irrespective of the source, current concentrations of total polycyclic aromatic hydrocarbons in the sediment samples were several orders of magnitude lower than the respective national Sediment Quality Guidelines (US EPA and ANZECC-ARMCANZ) at which it would constitute a risk to the environment.

However, as the sediment samples were collected approximately six months after the Montara oil spill was stopped, natural attenuation processes had reduced the concentrations and changed the patterns so that full source matching, as is commonly performed on non-degraded oils, was not possible.

The 2011 survey recorded hydrocarbons in fewer sediment samples, and at lower concentrations, than in the 2010 survey.

Natural hydrocarbon breakdown processes were occurring and the degraded state of the hydrocarbons again prevented identification of their source. For all samples, the measured concentrations of hydrocarbons were significantly below levels that national guidelines identify as a risk to the environment.

Studies in the Timor Sea and North West Shelf have shown there is a background presence of petroleum hydrocarbons. These could originate from natural seeps, the oil industry, passing ships or discharge from fishing boats.

Cartier Reef, with mixed hard and soft coral community

In addition to findings related specifically to the Montara spill, research undertaken in this study has:

- collected valuable baseline data on the three reefs and their context in the Timor Sea environment
- determined the overall composition of the reef communities has remained consistent between 2010 and 2011. Average live coral cover increased at all three reefs at a modest rate
- ascertained the coral bleaching event observed during the 2010 survey was largely absent in the 2011 survey
- confirmed coral reproduction and recruitment was occurring as expected at all three reefs and patterns of juvenile coral abundance at all three reefs were considered normal
- shown fish communities at Seringapatam Reef were significantly different from those at Ashmore and Cartier Reefs, suggesting a history of disturbance mostly likely from cyclones and coral bleaching events
- used multivariate analyses of species composition data, which showed the structure of fish assemblages at Seringapatam Reef were significantly different from those of both Ashmore and Cartier Reefs
- provided an increase in knowledge about coral sexual reproduction on Ashmore, Cartier and Seringapatam Reefs
- determined that live hard coral cover in 2011 at the Seringapatam, Ashmore and Cartier Reefs was within or above averages for live hard coral cover at the Great Barrier Reef.

Additionally, because the mean abundance of live coral at surveyed reefs was moderate but increasing, it is reasonable to expect gains in both live coral cover and coral recruitment at all locations.

This study highlights the great value of having a long-term monitoring program. This provides data which can be used to derive causal links for observed patterns. Most importantly, it would give researchers and managers the ability to determine whether observed changes are part of the natural variability in dynamic marine ecosystems, or reflect a response to the effects of anthropogenic, or human-caused, stressors such as the unplanned release of oil into the ocean.

The current survey design provides adequate statistical power to develop into a long-term monitoring program, with the ability to characterise natural variability in the abundance and diversity of key biota on the survey sites.

DISCUSSION

Reef coral community status

The 2011 repeat survey of shallow reefs was undertaken using the reef edge locations established in 2010, allowing a direct comparison of changes within and between reefs. Overall composition of the shallow reef benthos at Ashmore, Cartier and Seringapatam Reefs remained consistent between 2010 and 2011, with live hard coral and turf algae being the dominant groups.

Average live coral cover increased at all reefs at a similar modest rate, although with some variability between locations within each reef.

At the whole reef scale, the benthic community structure and pattern of change from 2010 to 2011 were very similar between the three reefs.

The mild coral bleaching observed in 2010 was largely absent in 2011, with only residual occurrences associated with individual coral colonies. The bleaching affected a minority of the coral community, although there was a differential effect between coral species and some individual species were strongly affected.

The two coral families most affected by bleaching in 2010, Acroporidae and Pocilloporidae, showed a significant reduction in their bleached status, with most colonies displaying normal pigmentation in 2011.

Average live coral cover increased at all reefs at a similar modest rate, although with some variability between locations within each reef.

Seringapatam Reef, the furthest away from the well head, was the worst affected by coral bleaching. This was the major significant difference in the status of benthic communities on these three reefs.

Research found the benthic communities were typical of shallow coral reefs and their condition was consistent with previous independent benthic surveys at Ashmore and Cartier Reefs (Skewes, et al. Richards, et al. 2009).

There was good supporting evidence region-wide thermal stress caused the coral bleaching, which was also observed at Scott Reef. Scott Reef was observed during the surveys to investigate how widespread the bleaching was.

A compounding effect from any pollution stress, though unlikely given the lower relative levels of bleaching at sites closest to the uncontrolled release, could not be absolutely ruled out. As the bleaching event was continuing at the end of the field survey period, the fate of bleached corals – which can recover, die, or become susceptible to disease after bleaching stress – remained unknown.

The presence of numerous adult sized colonies of species which were widely bleached in 2010 suggests many of the bleached corals survived and recovered. At Seringapatam, where pocilloporid species were most strongly affected by the 2010 bleaching, changes at each of the six monitoring locations showed a majority had experienced a decline in the abundance of this family. However, there was no clear correlation between the level of bleaching measured in this family at each location in 2010 and the amount of coral loss recorded in 2011.

Overall, it seems likely the duration and intensity of bleaching stress at Seringapatam in 2010 was greater than that experienced at Ashmore or Cartier Reefs, with subsequently greater loss of the more sensitive species at Seringapatam.

The rates of change in live coral were slower than would have been predicted from the most recent previous studies, but in keeping with older reports from other undisturbed reefs in the region. Unless these reefs face further disturbance – through cyclones, bleaching or pollution – the current monitoring should confirm significant coral growth continuing in the next few years.

Coral reproduction

Analysis into the gonad condition of more than fifty coral species from the Ashmore Reef and Cartier Islet was undertaken. High participation rates in normal gametogenesis, cell division which occurs as part of fertilisation and spawning, was typical of broadcast spawning species taking place at the surveyed reefs, with developing or mature gonads found in all but a few species.

The high levels of gametogenic activity seen in most species during the autumn and spring spawning periods confirms that reproduction is occurring on Ashmore, Cartier and Seringapatam Reefs since the 2009 Montara oil spill.

There are significant differences in gamete condition within and between reefs for many species, but there is no consistent difference between the two reefs closest to the uncontrolled release and the control reef.

It was likely there were broadcast spawning periods following full moons in mid-late September and February-March. Multiple species appear to spawn during the same months, but the peak month of multi-specific spawning has not yet been determined.

A number of brooding species can be common and important components of the coral community. These include *Acropora palifera*, *Pocillopora damicornis*, *Pocillopora verrucosa*, *Seriatopora hystrix* and *Stylophora pistillata*. Histological examination of these species revealed gametes at most developmental stages.

There is evidence of both synchrony within species and asynchrony between species within and between reefs, with some corals only spawning in the spring, some in the autumn and some species may spawn in both seasons.

The composition and mean number of coral recruits settling on the reef is very similar in Ashmore, Cartier and Seringapatam Reefs, providing no evidence recruitment is abnormally low at Ashmore and Cartier following the Montara spill. The overall levels of recruits per tile at these three reefs are low compared with some other regions, such as the Great Barrier Reef, but they are in the same range recorded at other Indian Ocean Reefs.

Overall, the patterns look normal and the two reefs closest to Montara, Ashmore and Cartier, did not show anything unusual in relation to juvenile coral abundance.

The survey of coral reproduction in April 2010 found very few coral species in reproductive condition. No colonies of females carrying eggs of the dominant acroporid species were found. Less than 10% of massive colonies in only a few common species, including *Goniastrea edwardsi* and *Favia pallida*, retained mature eggs.

However, in two common brain coral species, *Goniastrea retiformis* and *Favites abdita*, approximately 30% of the Ashmore populations contained some mature eggs when sampled during the first two days of field work in early April. Impacts on annual coral reproduction could not be determined for the majority of species. The survey (April 2010) probably occurred a month after the major annual spawning event, given March spawning was reported at other North West Shelf reefs that year (Gilmour, Stoddart, pers. comm. to AJH).

However, the very limited data on one species of hard coral observed to spawn during the study indicated normal spawning, gamete quality and embryological development.

A better characterisation of the timing of spawning and coral recruitment, along with improved measurement and modelling of currents, will be required to understand more clearly if reefs in this region are all highly isolated and rely on self-seeding for renewal, or are sustained by connections between both emergent and submerged reef habitats.

The patterns of juvenile coral abundance were found to be very similar in Ashmore, Cartier and Seringapatam Reefs, as was the case for newly settling coral recruits. This data suggests very similar processes of recruitment and post-settlement survival are operating at these reefs. The number of recruits are comparable with reefs supporting similar levels of spawning coral stock on the Great Barrier Reef.

Reef fish community status

The aim of this element of the study was to determine if there were any patterns in the size, abundance and composition of fish communities on reefs consistent with the effects of the Montara spill.

The densities, biomass and lengths of reef fishes were recorded at Ashmore, Cartier and Seringapatam Reefs in March 2011 using underwater visual census (UVC) and diver operated stereo video (DOV) techniques along the same transects used for the benthic study.

The survey recorded a total of 116,110 individuals from 309 species and 29 families. The UVC method recorded a total of 70,280 fishes from 258 species, while DOVs recorded 45,830 fishes from 199 species.

The difference in fish assemblage structures between Seringapatam Reef and both Ashmore and Cartier Reefs was mainly attributable to lower densities of the damselfishes *Chromis margaritifer*, *Chrysiptera rex* and *Plectroglyphidodon dickii* and higher densities of *Pomacentrus lepidogenys* and *Pomacentrus coelestis* at Ashmore and Cartier compared to Seringapatam Reef.

The greater abundances of *P. coelestis* at Ashmore and particularly at Cartier Reef are noteworthy because this species is known to recruit preferentially to degraded reef habitats. While the possibility that this is an impact from the uncontrolled release cannot be eliminated, these higher densities of *P. coelestis* could also be the result of disturbance events such as cyclones and coral bleaching which reduce cover of live coral. The relative influence of these different impacts cannot be determined without data on the benthic habitats prior to the uncontrolled release.

Fish communities displayed evidence other disturbances had affected community structure. Ashmore, Cartier and Seringapatam Reefs had higher proportions of herbivorous fishes, particularly surgeonfishes, than other studies have reported for the more distant Rowley Shoals. Herbivores typically increase in response to loss of live coral and its replacement by turfing algae. Higher abundances of herbivores on study reefs probably reflect a history of disturbance prior to the Montara oil spill.

While no major impacts on fish communities have been detected in the surveys, sub-lethal effects such as reduced growth may have occurred. In order to examine the possibility that the uncontrolled release may have affected juvenile fish growth rates, analysis of the age structure of fish communities would be required.

Herbivores typically increase in response to loss of live coral and its replacement by turfing algae. Higher abundances of herbivores on study reefs probably reflect a history of disturbance prior to the Montara oil spill.

As with corals, most fish larvae have a pelagic phase and they float around in the water column before settling on a reef. A healthy reef has lots of new 'recruits' (e.g. juveniles) both in terms of coral and fish. It is unusual to find no juveniles on a reef and, since they are usually more sensitive than adults, this suggests there has been a recent disturbance.

A size frequency distribution is a technique which describes the percentage of a population in different size classes. If the size frequency distribution is unusual and shows there are not many juveniles, then this suggests recruits of a particular age, corals or fish, are missing. This is not a desired situation.

Sediment hydrocarbon analysis

In studies of hydrocarbon concentrations in sediments at Ashmore, Cartier and Seringapatam Reefs, conducted five months after the discharge of oil and gas from Montara ceased, showed:

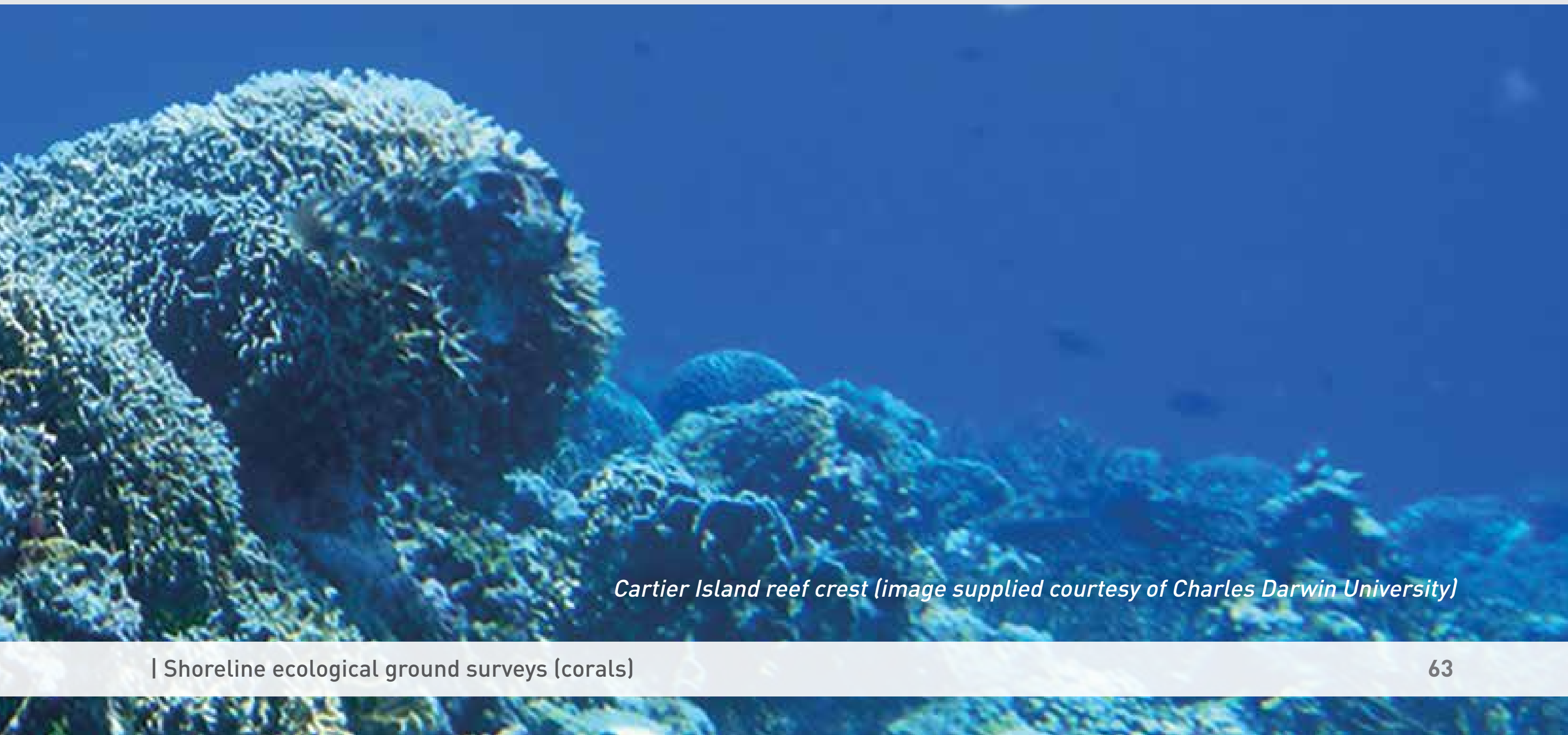
- hydrocarbon concentrations above detection limits in approximately 49% of samples
- a pattern of greater hydrocarbon levels at Ashmore and Cartier Reefs
- hydrocarbon concentrations detected were several orders of magnitude lower than that which would constitute a risk to the environment.

In the 2011 survey, conducted approximately 15 months after the discharge ceased:

- hydrocarbons were recorded in 35% of the samples. This compares to 2010, when hydrocarbons were detected in 50% of the samples
- there was still a pattern of greater hydrocarbon concentrations at Ashmore Reef
- hydrocarbon concentrations detected were several orders of magnitude lower than that which would constitute a risk to the environment.

Analyses from 2011 data showed the hydrocarbons had patterns typical of degraded oil, including a bimodal distribution, as also seen in the 2010 study.

In 2011, the sediments had high concentrations of diploptene, the biomarker for sulphate-reducing bacteria which are known to degrade hydrocarbons and the sterane and triterpane biomarkers expected for a degraded crude oil. Collectively, these results are consistent with weathering processes which have changed concentrations and chromatogram patterns.



Cartier Island reef crest (image supplied courtesy of Charles Darwin University)

Comparison with Great Barrier Reef data

Due to the lack of juvenile coral survey data at the surveyed reefs prior to the possible disturbance, a comparison was made with outer Great Barrier Reef reefs surveyed within the AIMS Long-Term Monitoring Program. These have similar live hard coral cover to the reefs studied in this survey.

Live hard coral cover at Ashmore and Cartier in 2010 was approximately 20 to 26% on the shallow and deep slope sites in 2010. Seringapatam had approximately 20% hard coral cover in the shallow and 36% at the deep slope. In 2011, mean hard coral cover increased by approximately 2 to 4% at all reefs.

The outer Great Barrier Reef reefs with 21 to 25% coral cover were found to have a mean juvenile density of 13.5 per metre^2 (± 5 SE [standard error]), reefs with 26 to 30% coral cover had a mean juvenile coral density of 14 per metres^2 (± 6 SE). Juvenile coral density per square metre at Ashmore with 10.2 (± 1.05 SE) was slightly lower than this average in 2010. Seringapatam with 12.9 (±1.3 SE) in 2010 was within the lower range.

All three reefs were within or above the Great Barrier Reef average in 2011.

This discussion was based on the S6.1 Shoreline ecological ground surveys corals research study (led by Dr Andrew Heyward and co-authored by a number of AIMS colleagues). PTTEP AA is grateful to AIMS and its employees for their contributions to this report.

Unless noted otherwise, all images in this discussion supplied courtesy of AIMS.

Corals at North Scott Reef (Image supplied courtesy of Charles Darwin University)

Shoreline ecological ground surveys (turtles and sea snakes)

CHARLES DARWIN UNIVERSITY

Charles Darwin University

Faculty of Engineering, Health Science and the Environment
School of Environment

Charles Darwin University researcher **Dr Michael Guinea** and colleagues undertook a study to assess sea snake and marine turtle populations, and the possible impact of the Montara 2009 oil spill on them. The study was also undertaken to investigate these species' detectable recovery, should they have been impacted by the spill.

Olive seasnake at Cartier Island

OVERVIEW

The study focused on the Scott Reef, Seringapatam Reef, Browse Island, Ashmore Reef, Hibernia Reef and Cartier Island in the Timor Sea. Special attention was given to Ashmore Reef and Cartier Island, being National Nature Reserves and Marine Protected Areas, and Scott Reef and Browse Island, being Western Australian Fauna Reserves.

The data set used to detect a change in the species present at each reef and their respective numbers is drawn from 256 days of surveys spanning almost 20 years. The study's specific objectives were:

1. to quantify the presence of *Environment Protection and Biodiversity Conservation Act 1999* listed fauna (sea snakes and marine turtles) and flora in the subject area pre-impact in order to determine the level of potential exposure to hydrocarbons
2. to identify and quantify the pre-impact status of fauna (e.g. nesting and breeding activity) and health of reefs
3. to identify and quantify the post-impact status of fauna (e.g. nesting activity) and health of reefs
4. to quantify recovery from any harmful effect of oil impact on flora such as seagrass, fauna, habitat or communities in the subject area.

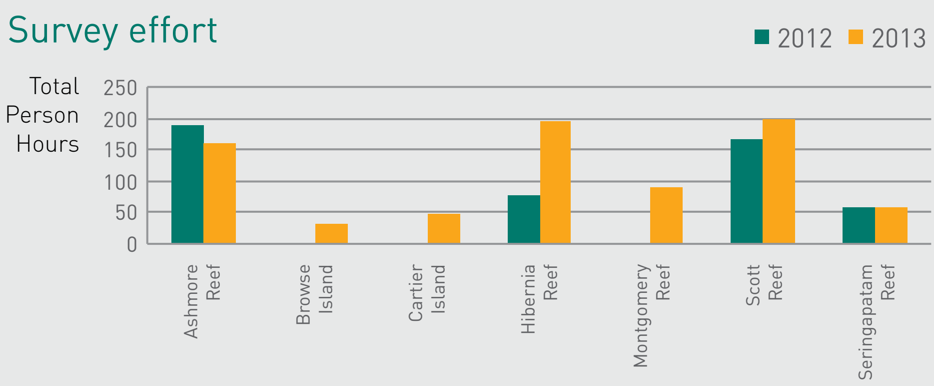
As the initial March 2012 survey was interrupted by bad weather and a cyclone, a subsequent survey took place in March 2013 to survey the remaining reefs potentially impacted by the Montara spill. Cartier Island and the control reef, Browse Island, both of which were not surveyed in 2012, were also included in the 2013 survey. The second survey, furthermore, reassessed the reefs which had been surveyed in 2012.

This study is a compilation of data collected and analysed from both surveys.

This was the most thorough sea snake and marine turtle survey of the reefs of the Sahul Shelf ever conducted. It augments, but also highlights, the paucity of information gleaned by many fragmented and opportunistic surveys over the past two decades.

The surveys in March 2012 involved 500 person hours of boat, foot and underwater surveys of four reefs of the Sahul Shelf. During this time the survey team conducted 98.2 kilometres of manta board surveys with a survey area of just over 877 hectares of reef crest and lagoonal habitats. A manta board survey involves a snorkeler holding onto a board behind a motor boat, who then records sea snakes and marine turtles within set areas. Boat survey transects over the reef flat and lagoons recorded data for over 286 kilometres within a survey area of 10,100 hectares.

In March 2013, the surveys covered seven reefs of the Sahul Shelf and Kimberley coast. More than 780 person hours by 11 individuals covered almost 100 kilometres of in- and on-water surveys and more than 10,000 hectares of reef flat, lagoon and reef crests.



Comparison between the effort involved in the 2012 and 2013 surveys of the Sahul Shelf

This was the most thorough sea snake and marine turtle survey of the reefs of the Sahul Shelf ever conducted.

KEY RESEARCH FINDINGS

The study found no visual evidence of hydrocarbon contamination on the beaches or on the reef flats surveyed. There is no evidence of the impact of the hydrocarbon release having a long term impact on sea snakes and marine turtles of the six reefs of the Sahul Shelf. Two of the reefs which were potentially impacted, Hibernia Reef and Cartier Island, had the highest species diversity and the greatest numbers of individuals.

Sea snakes

No sea snakes were observed on Ashmore Reef or on the neighbouring reefs within the Ashmore Reef Marine Park. Ashmore Reef, the reef most likely to have been impacted by the Montara spill, had few, if any, sea snakes prior to the hydrocarbon release.

With the exception of Seringapatam Reef, sea snake numbers were reduced from studies undertaken prior to 2012. In 2013, Seringapatam Reef had fewer sea snakes than in the previous year.

The analysis of sea snake population density and species diversity of the reefs of the Sahul Shelf and the likely impact of the hydrocarbon release indicated the potentially impacted site of Cartier Island had the highest sea snake densities of the six reefs.

Marine turtles

Marine turtle numbers were relatively stable compared with earlier surveys. Numbers of nesting turtles were consistent given the annual fluctuation in green sea turtle nesting numbers, with this survey period being after the peak of nesting in mid-summer.

Foraging green sea turtles were in expected numbers at Ashmore Reef's west and middle islands.

Aspects of the turtles' blood chemistry differed significantly from previous studies. All of the blood samples from foraging turtles had bilirubin concentrations in excess of the standard reference values for this species at Ashmore Reef and southern Queensland. The cause of this elevation and its implications to the health of the turtles remains unclear, but cannot be attributed to any hydrocarbon residue on the reef or seagrass.

Blood samples from the same species on Montgomery Reef, a control site, also had elevated bilirubin concentrations.

Dr Sanders and Dr Guinea, from Charles Darwin University, removing a skin biopsy from a Dubois' seasnake

DISCUSSION

Overview

The surveys aimed to quantify the presence of sea snakes, marine turtles and seagrass in areas of the Sahul Shelf which were likely to have been impacted by the Montara spill. The pre-impact status of the fauna and flora of the reefs from previous surveys by the author was compared with the post-impact status to quantify the recovery from any harmful effects of oil presence. Reefs were assigned a likelihood of potential impact status based on documentation at the time of the hydrocarbon release.

Potentially impacted reefs included Ashmore Reef, Cartier Island and Hibernia Reef. Reefs which were likely not to have been impacted were Scott Reef, Seringapatam Reef and Browse Island. This latter group were considered to be control or reference reefs. Ashmore Reef and Cartier Island are Marine Protected Areas under Commonwealth protection. Sandy Islet, Scott Reef and Browse Island are reserves under the control of the Western Australian Government.

Montgomery Reef on the Kimberley coast was chosen for its abundance of sub-adult green sea turtles as a control site from which blood samples could be collected. The samples were analysed for blood chemistry and to determine the concentrations of their electrolytes and enzymes (molecules at the heart of organisms' life-sustaining chemical transformations) and to compare them with samples collected from Ashmore Reef in 2012.

Habitat assessment consisted of inspecting the intertidal areas, seagrass beds and sediment cores from nesting beaches. There was no visible evidence of hydrocarbon residue on any of the beaches, seagrass beds, corals or intertidal reef flats.

The Sahul Shelf is broadly defined as the shelf of shallow seas to the west of the Tiwi Islands to the edge of the Australian continental plate, north west of Australia, where water depths begin to increase into the underwater plain on the deep ocean floor. The Shelf's approximate area is 400,000 kilometres^2.

Hibernia Reef, Ashmore Reef, Cartier Island, Seringapatam Reef, Scott Reef and Browse Island are on the Sahul Shelf. Montgomery Reef is located on the Kimberley coast. Although not on the Sahul Shelf, it is adjacent to the Timor Sea and was expected to have sea turtles and sea snakes similar to those found on the Shelf. It was not impacted by the Montara oil spill in 2009 and was classified as a control site.

(Top to bottom) Researcher with olive seasnake at Hibernia Reef; olive seasnake, Aipysurus laevis, *on Seringapatam Reef; researcher measuring the curved carapace length of a green sea turtle, after laying on Ashmore Reef; sub-adult green sea turtle at Ashmore Reef*

Sea snakes – Montara Environmental Monitoring Program

The surveys assessed the sea snake populations by:

- paired manta board transects of the reef crests and lagoons
- standard snorkel surveys for fixed periods of time in known locations
- foot transects at low tide over the reef flat
- boat transects over the reef and lagoon at high tide
- night spotlighting of the reef flats, reef crest and deeper waters adjacent to the reef.

No sea snakes were seen on Ashmore Reef in either of the surveys. Sea snake numbers have dwindled on Ashmore Reef since 1998 to a level where sea snakes have not been seen on the reef for some years. Sea snakes were not recorded on Browse Island in this survey nor had they been reported in any previous surveys.

Sea snake numbers have dwindled on Ashmore Reef since 1998 to a level where sea snakes have not been seen on the reef for some years.

The numbers of sea snakes on the other reefs varied, although the survey effort was similar in each case, with the exception of Hibernia Reef which was one of the reefs where sea snakes were abundant.

Seringapatam was the only reef which had a decline in sea snake numbers between the two surveys.

Marine oil spills in tropical Australian waters have been linked to the deaths of sea snakes (AMSA 2010). The cause of the death of sea snakes collected for post-mortem examination from the region of the Montara oil spill was inconclusive (Gagnon 2009). Lethargic, possibly ill, sea snakes were reported in the slick emanating from Montara (Watson, Joseph, et al. 2009).

The Sahul Shelf contains the world's greatest diversity of Aipysurine sea snakes (Guinea 2003). Yet only hydrophine sea snakes, *Hydrophis* and *Acalyptophis*, were collected from the oil slick or the region of the spill (Gagnon 2009).

Hydrophine sea snakes, because of their behaviour, may be more susceptible to the adverse effects of oil on the sea surface.

Seven species of sea snake were encountered out of 17 species recorded from the reefs of the region. The diversity of sea snakes comprised generalist feeders such as Aipysurus species as well as specialist feeding Hydrophine species.

Not all species were found on all reefs. The two endemic species of sea snakes belonging to the genus Aipysurus were not encountered in either survey.

The sea snake population density on some reefs such as Seringapatam Reef varied between surveys with no obvious explanation for the variations. The sea snake populations are dynamic and require more regular monitoring to provide security in the population status.

Missing from this analysis is a clear indication of how the populations of sea snakes fluctuate over time and the likely causes of declines as seen at Ashmore Reef and now, possibly, Seringapatam Reef.

Ashmore Reef has a reputation for sea snake abundance and species diversity. Hibernia Reef on the Sahul Shelf shared the diversity of sea snake species with Ashmore Reef (Guinea 1993b). Other reefs in the region like Cartier Island, Seringapatam Reef, Browse Island and Scott Reef have had fewer species recorded previously.

Historically, Ashmore Reef and Hibernia Reef hosted almost identical species diversity. Surveys in 2005 and 2006 revealed a decrease in species diversity at all locations including Scott Reef. The results for Ashmore Reef indicate commonly encountered species were rare in 2006 (Francis 2006) and absent thereafter (Efles, et al. 2013).

The distance between reefs on the Sahul Shelf, and the deep water between reefs, inhibits sea snake migration and supports the concept of sea snakes from each reef forming a discrete management unit for each species. Observations on the morphology of the sea snakes of each of the reefs indicate distinctive colourations which may indicate restricted gene flow between reefs.

Sea snakes – overview

The distance between reefs on the Sahul Shelf, and the deep water between reefs, inhibits sea snake migration and supports the hypothesis that sea snakes from each reef may form a discrete management unit for each species.

Sea snakes are a diverse group of marine reptiles forming at least three evolutionary lineages (Hydrophine, Aipysurine and Ephalophine) in Australian waters with another two lineages in Asian waters (Guinea 2003; Heatwole and Cogger 1994).

From surveys of the effects of the oil spills in the Arabian Gulf during the conflicts in the early 1990s it has been suggested sea snakes were the second most vulnerable species ahead of marine turtles (Tawfiq and Olsen 1993).

Being air breathers with a diet of either fish or fish eggs, sea snakes live in shallow, coastal, tropical waters of the Indian and Pacific Oceans. An exception to this is the yellow bellied seasnake (*Pelamis platurus*), which lives a pelagic life feeding on small fish which shelter beneath the motionless snake, which resemble driftwood.

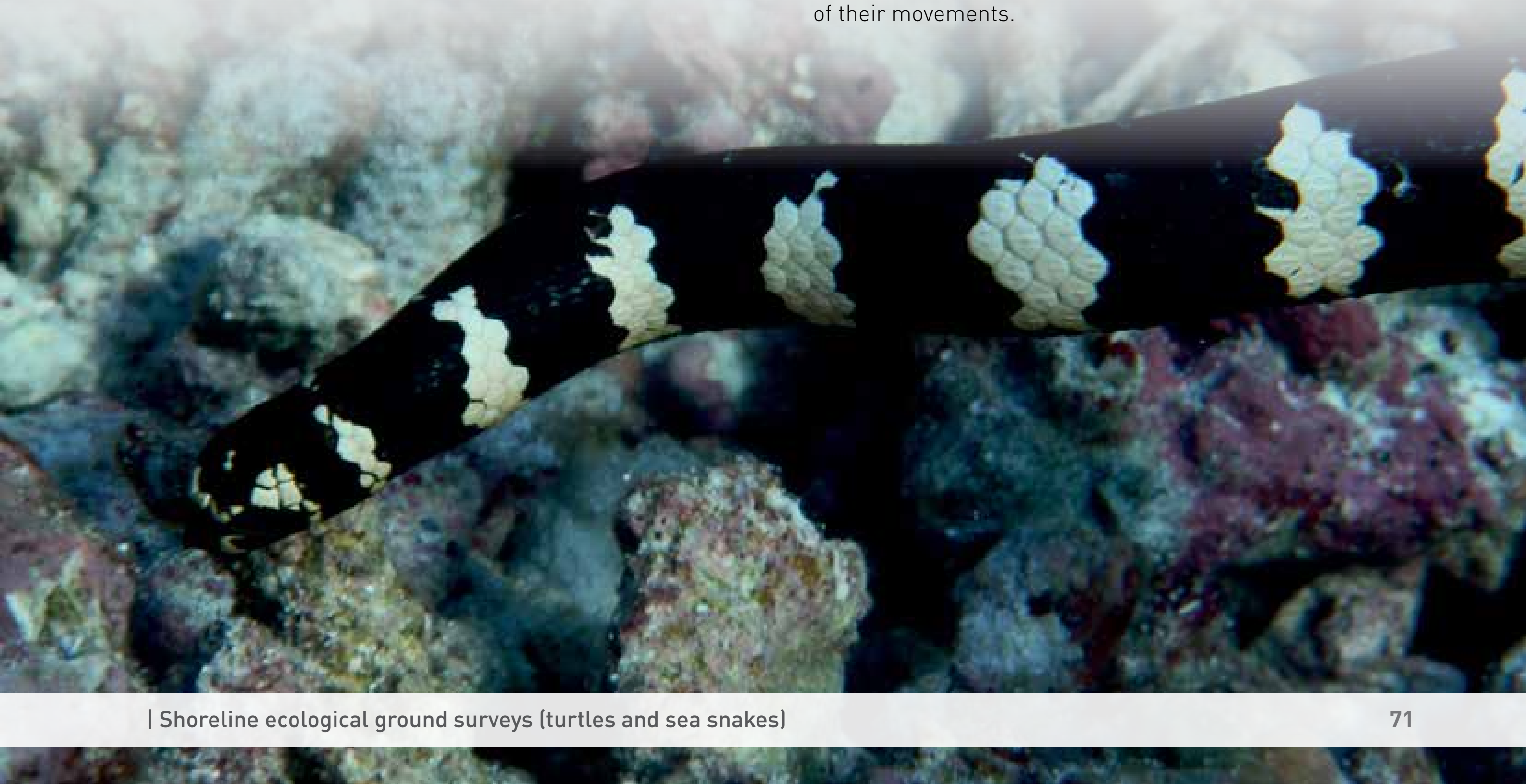
The majority of sea snake species feed on the sea floor and rise to the surface to breathe. Up to 40% of the oxygen requirement of the yellow bellied seasnake, however, diffuses from the sea water through its skin (Heatwole and Cogger 1994).

The sea surface is also where sea snakes rest, bask and drink freshwater during showers of rain. The Hydrophine sea snakes tie knots with their bodies and squeeze through the coils to remove parasites and to slough their skin. All the sea snake species living in Australian waters give birth to live young at sea.

Given their need for shallow waters with a plentiful supply of fish, the seas of northern Australia abounded with sea snakes, fascinating the early navigators including William Dampier and Phillip Parker King (Hordern 2004).

Sea snakes which inhabit the coral reefs live out their lives within a few hectares with very little movement between reefs (Burns and Heatwole 1998; Burns 1984; Lukoschek 2007; Lukoschek, Heatwole, et al. 2007; Lukoschek and Keogh 2006; Lukoschek, Waycott, et al. 2007). Essentially, once a species becomes resident on a reef, active dispersal and migration between reefs ceases.

Species living between reefs are believed to move to some extent with ocean currents, yet still remaining within unspecified home ranges. The seasonal presence of species in more temperate regions is associated with the southern movement of tropical waters (Cogger 1975; Limpus 1975). There has been no study of sea snake migration on the open water species to determine the extent of their movements.



Marine turtles – Montara Environmental Monitoring Program

Sea turtles were assessed by recording their presence during the manta board surveys and foraging numbers by boat surveys over the reef flat at high tide.

Possible hydrocarbon contamination of the diet of foraging green sea turtles was assessed by analysing blood samples taken from sub-adult turtles which were resident on Ashmore Reef, a site potentially impacted by the Montara spill and Montgomery Reef, the latter as a control site.

Beaches were monitored for adult turtles and their nesting success assessed along with the hatching success of hatchlings which have emerged from recent nests.

Marine turtle nesting was recorded for Sandy Islet, Scott Reef, Browse and Cartier Islands and the islands of Ashmore Reef. Eight individual green sea turtles nested on Ashmore Reef's west island over the four nights of the first survey and 12 nested during the time of the second survey.

Foraging green sea turtles were in expected numbers at Ashmore Reef with reliable samples obtained from 16 individuals. In 2013, 12 individuals were caught and blood samples collected from Montgomery Reef, a control site. Several of the blood parameters were significantly different from, but within the reference values, of those reported previously from foraging green sea turtles at Ashmore Reef and the literature.

The liver-function indicating compound, bilirubin, was the exception in having values in excess of those from previous studies at Ashmore Reef and from the literature for green sea turtles. The blood samples from green sea turtles at Montgomery Reef, the control site, had similar elevated bilirubin values.

It has been postulated that marine turtles in this survey should have displayed external symptoms of liver abnormalities, such as jaundice and lethargy, had they been affected by the oil. Such was not the case with the 25 green sea turtles captured at Ashmore Reef.

The samples collected from the 12 individuals from Montgomery Reef provided an interesting insight to the reference values. Not only were the bilirubin values large as in the Ashmore samples from 2012, but also there appeared a temporal change in the values of potassium, glucose, urea and uric acid collected by an individual late in the afternoon, compared with those captured at dawn, as they moved onto the reef to feed. These values would have been treated as outliers and excluded from the previous studies (Whiting, Guinea, et al. 2007, Flint, Morton, et al. 2009).

These studies present putative reference values based on some tens of individuals rather than a far larger dataset.

Foraging marine turtles are present at all times of the year on Ashmore Reef, but numbers of marine turtles on the reef flat increase with the arrival of the breeding females and males into the reef environment with the approaching summer nesting season (Guinea, Whiting, et al. 2005; Whiting and Guinea 2005c). The post-mortem examination of a deceased juvenile green sea turtle, collected at the time of the spill, was inconclusive as to the cause of death (Gangnon and Rawson 2010b).

There is no evidence of negative impact on the numbers of juvenile green sea turtles on Ashmore Reef from the Montara oil spill in 2009. For as yet unexplained reasons, Ashmore Reef still retains large numbers of sub-adult green sea turtles. Scott Reef and Seringapatam Reef, with almost identical intertidal habitats, support relatively few foraging marine turtles as indicated in the current surveys.

Breeding marine turtles which migrate to, and from, the nesting beaches on the Sahul Shelf from Australian coastal waters may come into contact with surface oil slicks with possible harmful effects, but this was not detected in this survey.

The nesting green sea turtles visiting Ashmore Reef, Cartier Island, Browse Island and Scott Reef are from feeding grounds scattered over northern Australia – from the Gulf of Carpentaria to the Pilbara coast (Guinea 2009; Guinea, Whiting, et al. 2005). As they utilised stored fat reserves during the nesting season, their diet is unlikely to be influenced by hydrocarbon in the vicinity of the nesting beach.

Breeding marine turtles which migrate to, and from, the nesting beaches on the Sahul Shelf from Australian coastal waters may come into contact with surface oil slicks with possible harmful effects, but this was not detected in this survey.

This Sahul Shelf to mainland migration was demonstrated by one of the green sea turtles tagged on 8 March 2012, while nesting on Ashmore Reef's west island, being later captured by Aboriginal hunters in King Sound in the Kimberley of Western Australia.

Marine turtles may have been impacted beyond the area of the hydrocarbon release due to their migratory behaviour. Although the three control reefs were not impacted, the marine turtles living on the reefs and nesting on the beaches may have been potentially impacted through their diet or contact at a location affected by the Montara spill.

Marine turtles – overview

The reefs and waters of the Sahul Shelf support various life stages of marine turtles. They belong to several genetic sub-populations from Indian Ocean countries, but dominated by those with their nesting beaches in northern and Western Australia.

In contrast to sea snakes, marine turtle species have complex life cycles involving active dispersal and several stages and periods of migration. Two discrete genetic sub-populations nest on beaches of the Sahul Shelf islands. Ashmore Reef and Cartier Island host a common gene pool, as do Scott Reef and Browse Island. Both have a similar life cycle (Figure 1).

The current understanding of the life cycle begins with hatchlings moving from the nest above the high water mark to the beach and beyond to oceanic and coastal habitats, before returning 30 to 50 years later to the region of their birth to breed. In the case of Scott Reef turtles and Ashmore Reef management units, this life cycle may involve feeding and moving between reefs in the tropical Indian Ocean and northern Australia.

During the breeding season, the turtles from the Scott Reef and Ashmore Reef management units, which are genetically isolated populations, mate near, nest at and spend the inter-nesting periods associated with their respective reefs.

Also on the reef at breeding season, and throughout the year, are the non-breeding sub-adult and adult turtles which forage and reside on the reefs. Genetic studies (Dethmers, FitzSimmons, et al. 2005) have revealed these belong to other management units in Western Australia and the Indian Ocean.

Within the generalised life cycle, there are at least two cycles which involve breeding females using the reefs, lagoons and beaches at Scott Reef:

- the female nesting cycle – every two to eight years when female green turtles migrate from their foraging grounds to Ashmore Reef and Scott Reef respectively to breed
- the inter-nesting cycle – females spend two to three months within the vicinity of the nesting island moving only short distances of some tens of kilometres or less and nesting from three to six times during the nesting season every eight to 16 days.

Female nesting cycle

The female nesting cycle involves an individual female attaining sufficient body fat and reserves in the foraging grounds to become reproductive (Hamann, Limpus, et al. 2003). An unknown trigger initiates her migration, of up to several thousand kilometres, from the foraging grounds to a mating area close to her natal beach (Miller 1997). This migration coincides with similar movements by males (Hamann, Arthur, et al. 2003).

After mating, the female turtle becomes unreceptive to further courtship (Booth and Peters 1972) and moves closer to the nesting beach over the next few weeks. At this point, she enters the inter-nesting cycle (Hamann, Limpus, et al. 2003). After laying several clutches of eggs, and having depleted the fat reserves and ripe ovarian follicles, the females undertake post-breeding migration to the foraging grounds (Hamann, Arthur, et al. 2003).

Being herbivorous, the time until the next breeding migration depends on the richness of the algal beds and seagrass pastures on the foraging grounds (Miller 1997). Typically, at least three years or more is required to replenish the fat reserves and to develop mature ovarian follicles (Arthur, McMahon, et al. 2009; Miller 1997). The time between successive reproductive periods is called the remigration interval.

First time nesters, or neophytes, are thought to undertake a breeding migration when they have sufficient fat reserves which have accumulated over many years (Hamann, Limpus, et al. 2003; Miller 1997).

They respond, however, to the same triggers which initiate the reproductive migration of seasoned nesters and make the journey to their natal beaches (Miller and Limpus 2003; Plotkin 2003). In nesting seasons, following a period of low productivity on the foraging grounds, the neophytes remain capable of making the nesting migration whereas recently returned females may lack body condition (Miller and Limpus 2003).

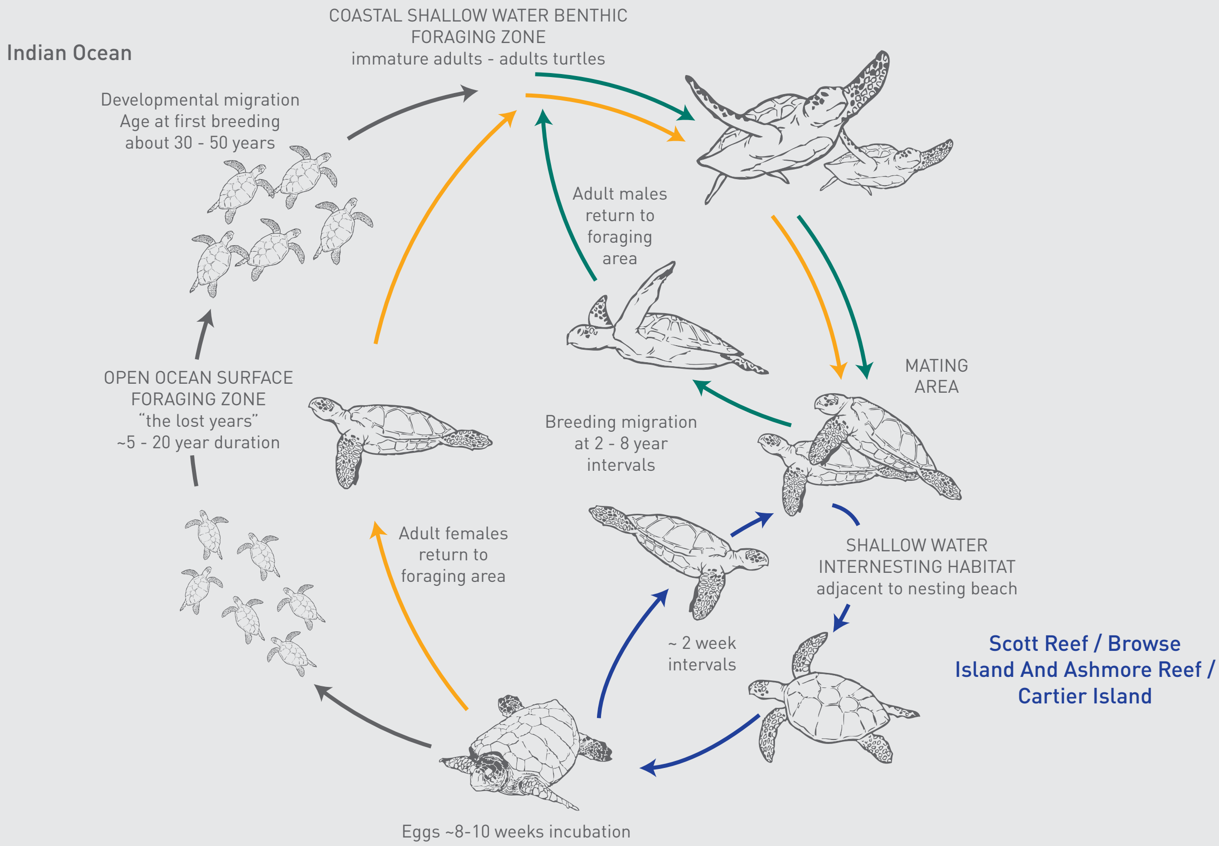


Figure 1. Generalised life cycle of marine turtles showing the female cycle of two to eight years (gold), the inter-nesting cycle of eight to 16 days, the nesting activities on Ashmore and Scott Reefs (purple) and the pelagic and neritic foraging stages (grey) (Source Miller 1997)

Smaller, and presumably younger, marine turtles may therefore have a disproportionately higher representation among the nesting population when fewer turtles make the breeding migration (Hamann, Limpus, et al. 2003; Limpus, Miller, et al. 2003a). In years with little nesting, the population may comprise individuals whose foraging grounds are closer and require fewer body reserves, individuals which have not nested for some time and individuals which are residents of very productive foraging grounds (Hamann, Arthur, et al. 2003; Miller 1997; Miller and Limpus 2003).

Once nesting starts, the inter-nesting cycle is approximately two weeks in duration and depends, in part, on water temperature (Hamann, Arthur, et al. 2003; Hirth 1993; Miller 1997).

The female occupies an inter-nesting habitat after each nesting event. For green sea turtles, these inter-nesting habitats are defined by their function rather than by location. Satellite tracking has demonstrated during the inter-nesting period female turtles visit different substrates, occupy different depths and may move up to tens of kilometres from the nesting beach (Alvarado and Murphy 1999; Bell, Seymour, et al. 2009; Hays, Glen, et al. 2002; Limpus, Miller, et al. 2003a).

Turtles which remain close to the nesting beach also appear to move through several near shore habitats during the inter-nesting interval (Limpus 2008; Limpus and Reed 1985).

Foraging turtles

Other age classes present on the reefs of the Sahul Shelf comprise the hatchlings of the present breeding season. These leave the nests above the tide line, then cross the beach and reef flat and enter the open ocean.

Any impediment to their movement across the beach and reef flat, such as hydrocarbon deposits, jeopardises their survival by restraining their movement.

While crossing the beach and reef flat, they are vulnerable to many predators including ants, crabs, octopus, fish, birds and even sea anemones.

Juvenile turtles in the 35 to 50 cm size are recently recruited to the reef from the open ocean. New recruits are characterised by having brilliant white plastrons, or belly plates, and the trailing edges of the scales are very sharp, having not been in contact with the sea floor, sand or coral (Whiting and Guinea 2005a; Whiting 2000). Turtles of this size with darker plastrons have been resident on the reef for some time.

Also resident on the reef are larger turtles not yet of breeding size (80 cm) and may not have the external sexual characteristics of adult males. These are considered sub-adult turtles.

Additionally, there are adult male turtles easily recognised by their elongated tail, as well as short tail adults comprising migrating breeding females in their pre-nesting and inter-nesting habitat, plus non-breeding resident females. From this collection of marine turtles, the dark plastron juveniles and the sub-adults are groups which may have been resident on the reef for some years. Their body tissues, therefore, may indicate some impact caused by contact with any hydrocarbon release in the area.

This discussion was based on the S6.2 Shoreline ecological ground surveys (turtles and sea snakes) research study. It was enhanced by discussions with Charles Darwin University's Dr Michael Guinea. PTTEP AA is grateful to Dr Guinea and Charles Darwin University for their contributions to this report.

All images in this discussion supplied courtesy of Charles Darwin University.

Shoreline ecological ground surveys (seabirds and shorebirds)

Monash University
School of Biological Science

Monash University researcher **Dr Rohan Clarke** undertook a study on seabirds and shorebirds at Ashmore Reef, Cartier Island and Browse Island in the Timor Sea to determine if there were any changes in bird populations due to the Montara oil spill.

White-tailed Tropicbird adult in flight over West Island, Ashmore Reed

OVERVIEW

Further objectives of the research study were to:

- identify and quantify the pre-impact status of seabirds and shorebirds and the health of flora at Ashmore Reef, Cartier Island and Browse Island (also referred to as the reserves)
- collate and interpret existing data on seabird and shorebird numbers as they relate to terrestrial environments at the reserves
- undertake a field survey of breeding seabirds and migratory shorebirds as soon as possible after the Montara oil spill, utilising standard methods to provide a measure of seabird and shorebird status within the reserves. This included a survey of nesting areas for seabirds, and roosting and feeding areas for shorebirds
- explore existing long-term data sets that identify the most appropriate statistical analyses to detect changes in breeding seabird and migratory shorebird numbers, due to the Montara oil spill
- utilise the above information and knowledge to develop and refine a post-impact monitoring program for seabirds and shorebirds occurring within the reserves.

At the time of writing in late 2013, seven surveys have been undertaken at the rate of two per year. Three more are scheduled to occur. The first monitoring survey took place in April 2010 and the final one will take place in November 2014.

The five year period was employed because it was considered the minimum timeframe over which seabird and shorebird counts at these locations would provide a defensible measure of population trends. This will provide data to enable the detection of trends, as well as future significant changes in total seabird and shorebird numbers within the reserves.

The initial study incorporated an extensive amount of data collated by Dr Clarke and colleagues which had not previously been published. The Montara Environmental Monitoring Program provided the impetus to collate this data into a usable and scientifically rigorous form and it informs findings and assertions made in this study.

Efforts to quantify the breeding populations of all species of seabird and the populations of key migratory shorebird species occur during each visit. The survey methods are those of the initial field survey.

The twice-yearly approach to monitoring was employed as it was considered the minimum number of visits necessary. This is because:

- seabird species breeding on Ashmore Reef islands do so at different times of year. For example, the wedge-tailed shearwater breeds from October to March, whereas the common coddy generally breeds from April to July. Additionally, some seabird nesting events may be aseasonal and do not occur at any regular time of the year, making their timing difficult to predict, for example in the cases of the sooty tern and crested tern. The twice-yearly approach increases the probability of detecting these events and adequately documenting them
- shorebird numbers are known to fluctuate with the seasons at Ashmore Reef, with peak abundances of shorebirds reported from October to March. Twice annual visits provide opportunities to document peak numbers of shorebirds during both the wet season, when adult shorebirds are present and the dry season, when adults have departed and young birds of some species remain

Nest attendance duties by female great frigatebird (adult despite darker grey throat) on Middle Island, Ashmore Reef

- the first period, mid-April to mid-May, coincides with the maximum numbers of breeding seabird species being present on the reserves, particularly at Ashmore Reef. Surveys at this time should provide data that underpin population trend and change point assessment for the majority of breeding seabirds
- the second survey period during November each year provides the opportunity to:
  - survey migratory shorebirds at a peak time
  - assess several seabird populations which would be inadequately covered in April, for example the wedge-tailed shearwater
  - count used nests of several other seabirds, such as the lesser frigatebirds and black noddies, to provide a second assessment of the breeding population size for those species
  - provide population-wide counts of all seabirds at a time comparable with the bulk of existing data collected since 1996 (Clarke, et al. 2011, Milton 1999; 2005, Bellio, et al. 2005)
- it provides an opportunity to gather more extensive time-series data, which is essential to identifying trends in populations, on year-round resident breeding species such as the eastern reef egret and brown booby.

Seabird species such as the wedgetailed shearwater and the common noddy breed on Ashmore Reef at different times of the year, while species such as sooty tern and crested tern nest irregularly.

Data generated from the continuing research has enabled more detailed insight into birdlife.

The closest seabird and shorebird terrestrial habitats to Montara are Cartier Island, 105 kilometres to the west, and Ashmore Reef, 157 kilometres to the west-north-west. Browse Island lies 195 kilometres to the south west of Montara.

These reserves support internationally significant numbers of breeding seabirds and migratory shorebirds, with all species variously listed under the Environment Protection and Biodiversity Conservation Act 1999. Ashmore Reef is also a Ramsar wetland of international importance.

Twenty breeding species of seabird and heron are known to exist on Ashmore Reef and nearby islands, indicating an exceptionally high diversity. Numbers of breeding seabirds are now known to exceed 100,000 individuals during a single year.
Up to 33 species of migratory shorebirds and 18,000 individual shorebirds have also been documented on the reserves.

For most species of seabird, the study focuses on breeding pairs. This is because counts of active nests are highly repeatable and are thus the most stable indicator of trends in seabird populations. Monitoring the breeding population is also particularly valuable in the context of oil spills, as many seabirds take a long time to reach maturity and then breed for an extended period when finally mature.

Data gathered during the post-impact monitoring period was compared with pre-impact data extending back to 1998. Control data for migratory shorebirds collected from nearby mainland sites will also be incorporated into the final analyses to be conducted following the November 2014 survey.

For most species of seabird, the study focuses on breeding pairs. This is a particularly valuable approach in the context of oil spills, as many seabirds take a long time to reach maturity and then breed for an extended period when finally mature.

Adult male brown booby attending medium/large chick

KEY RESEARCH FINDINGS

The research detected no signs of oil contamination. By April 2010 there was no visible evidence of oil on any live or deceased birds or on nest contents. Additionally, no impact on terrestrial vegetation was observed.

The research has also:

- generated a robust baseline of data to inform ongoing monitoring and the detection of significant impacts (if any) on birds and terrestrial habitats within the reserves
- identified the potential for long-term impacts on bird populations from oil spills
- established a monitoring protocol for seabirds and shorebirds, terrestrial habitats and vegetation condition
- generated detailed information concerning individual seabird species at Ashmore Reef and how aspects of their biology relate to the potential for long-term impacts.

The data will be critical in determining the nature of activities which will occur in the Browse Basin. It will help the Australian Government, regulators and industry in managing resources in the area and could impact on state and federal legislation.

Prior to this study there was no standardised method for capturing data on birdlife at the Ashmore Reef.

When the larger amount of data, including that available pre-Montara oil spill, was compiled, it was clear the seabird population at Ashmore Reef was increasing prior to the Montara oil spill. The initial research findings as they relate to seabird population trends suggest this population increase has also continued since the Montara oil spill.

In April 2012, for instance, for the first time more than 100,000 seabirds were observed breeding on Ashmore Reef. By April 2013, there were 107,000 breeding pairs of seabirds. This is from a baseline of 75,000 breeding seabirds in April 2010.

When the larger amount of data, including that available pre-Montara oil spill, was compiled, it was clear the seabird population at Ashmore Reef was increasing prior to the Montara oil spill. The initial research findings as they relate to seabird population trends suggest this population increase has also continued since the Montara oil spill.

A portion of a crested tern colony that contained 2368 adults, East Island, Ashmore Reef

DISCUSSION

Characteristics of monitoring study areas

Ashmore Reef National Nature Reserve and Cartier Island Marine Reserve protect marine ecosystems with high biological diversity (Commonwealth of Australia 2002). Ashmore Reef contains four lightly vegetated islands, with a total land area of approximately 54 hectares, and several additional sandbanks which rise above the high water mark.

Within its fringing reef, Cartier Island Marine Reserve contains a single sand cay, of about 2 ha, devoid of vegetation (Pike & Leach 1997, R. Clarke pers. obs.).

Browse Island is also situated within a relatively small fringing reef. The northern and eastern shores of Browse Island consist of low lying sparsely vegetated eroded coral rubble, while the remainder of the island is more elevated, at between five and ten metres high, and vegetated with herbs and low shrubs (R. Clarke pers. obs.).

Ashmore Reef supports a large population of seabirds, including some of the most important seabird rookeries on the North West Shelf (Commonwealth of Australia 2002, Milton 2005). Many of these seabirds are breeding visitors and are present in large numbers on a seasonal basis.

Large colonies of sooty terns, crested terns, common noddies, lesser frigatebirds and brown boobies breed on Ashmore Reef's East and Middle Islands. Smaller breeding colonies of wedge-tailed shearwaters, masked and red-footed boobies, great frigatebirds, little egrets, eastern reef egrets and black noddies also occur (Milton 2005, Clarke, et al. 2011).

Red-tailed tropicbird adult attending medium-sized chick at base of mature Argusia argentea *shrub on West Island, Ashmore Reef*

Ashmore Reef is a Ramsar-listed wetland. The Ramsar Convention is an international treaty for the conservation and sustainable utilisation of wetlands of international significance. Ashmore Reef has also been designated an important bird area by BirdLife International because it supports exceptionally large numbers of migratory or congregatory species (BirdLife International 2010).

Prior to this research taking place, there was limited information available on seabird populations at Cartier Island and Browse Island, though Crested Terns had previously been reported to nest at Browse Island (Smith, et al. 1978). Prior to guano extraction in the 19th century this island likely supported significant numbers of other tropical seabirds (see Serventy 1952).

Prior to the seabird monitoring study detailed here there was almost no monitoring of seabirds in the north west of Australia, so most information is new.

Ashmore Reef, Cartier and Browse Islands are also important foraging areas for migratory shorebirds visiting the region from the northern hemisphere. Shorebird numbers are highest between October and April, though large numbers of shorebirds are present year round as many species stay over winter in their first years of life (Australian National Parks and Wildlife Service 1989, Higgins & Davis 1996). The extensive sand flats exposed at low tide provide foraging opportunities for internationally significant numbers of some species including grey plover and sanderling (Clarke 2010).

Shorebirds, on the other hand, have been intensively monitored on the mainland at coastal sites south of Broome for over a decade. The data gathered on shorebirds at Ashmore has added signficantly to our regional understanding of this group, while focusing on trends rather than a broader understanding of shorebird ecology.

Tropical seas tend to have low productivity and diversity compared to temperate marine environments. The high diversity found on Ashmore, therefore, is exceptional. The indicators are that around Ashmore the waters are productive relative to other comparable areas, with a high biomass of food.

Summary of seabirds and shorebirds on Ashmore Reef (2010-2013)

	2010	2011	2012	2013
Total seabirds (April survey)	75,000	82,484	100,968	107,867
Total shorebirds (November survey)	12,151	12,743	10,435	

Oil's impact on seabirds and shorebirds

Breeding seabirds at the reserves may have been directly exposed to oil via a number of potential pathways. Birds foraging at sea have the potential to directly interact with oil on the sea surface some considerable distance from the marine reserve in the course of normal foraging activities. Surface plunging species such as terns and boobies and species that readily rest on the sea surface, such as shearwaters, are most at risk.

As seabirds are top-order predators, any impact on other marine life, for example fish kills, may disrupt and limit food supply. Any direct impact of oil on terrestrial habitats within the reserves, including the shorelines of islands and sandbanks, has the potential to contaminate birds at the breeding sites.

The monitoring of trends in breeding population size for a suite of seabird species is considered the minimum requirement to assess potential impacts from the Montara spill on seabirds that breed within the reserves.

Shorebirds are likely to be exposed to oil when it directly impacts on the reef, associated sand flats and shorelines within the reserves. As shorebird species at the reserves forage for invertebrates like sand worms and crabs, on exposed flats at lower tides (Higgins & Davis 1996), there is the potential for both direct impacts through contamination of individual birds through ingestion or soiling of feathers, and indirect impacts through the contamination of foraging areas that may result in a reduction in available prey.

The monitoring of trends in shorebird population sizes would be a minimum requirement to assess potential impacts from the Montara spill on those shorebird species which regularly occur within the reserves.

Vegetated sandbank to the east of East Island, Ashmore Reef. The dominant grass visible in this image is Lepturus repens

Ashmore Reef – an ecological refuge

Ashmore Reef has always been one of the most significant seabird breeding islands in the Timor Sea. Prior to the 1980s it was not policed at all. Indonesian fishermen used to frequent the island and even though an Australian-Indonesian agreement stated no hunting of seabirds or turtles could take place there, it was a traditional practice for this to occur.

Since the mid-1980s, the year-round presence of Australian Customs and Department of Sustainability, Environment, Water, Population and Communities representatives has allowed the seabird population to gradually build.

In the past few years, the seabird population had recovered such that in excess of 100,000 individuals are now known to breed at Ashmore each year. Hunting pressure appears to have driven many seabird colonies to extinction in adjacent areas of Indonesia during the same period. The mixed fortunes of seabird colonies in the region underlines the importance of Ashmore as an ecological refuge.

The shorebirds' long road

With over 10,000 shorebirds at Ashmore Reef, it is a nationally and internationally significant site for species such as bar-tailed godwit, grey-tailed tattler, ruddy turnstone, red-necked stint, greater sand-plover and grey plover. The shorebirds occurring at Ashmore and other nearby locations are almost entirely migratory. They visit Ashmore for a non-breeding period of about eight months.

Most species breed in the Arctic tundra, which they reach by a series of extended flights of two to three days, broken by rest and feeding periods of several weeks at important stop over sites such as the shoreline of the Yellow Sea in China. Before departing for this arduous migration, individuals develop a thick layer of fat over their body. This serves as their 'fuel' for this remarkable flight.

This discussion was based on the S6.3 Shoreline ecological ground surveys (seabirds and shorebirds) research study, but was enhanced by extensive discussions with Monash University's Dr Rohan Clarke. PTTEP AA is grateful to Dr Clarke and Monash University for their contributions to this report.

All images in this discussion supplied courtesy of Dr Rohan Clarke.

Oil fate and effects assessment – spill trajectory analysis

Asia-Pacific ASA

Asia-Pacific ASA researchers **Dr Brian King** and **Trevor Gilbert** undertook a study which aimed to document the location of oil released from the Montara oil spill. The data was gathered from field and overflight data and satellite observations, and integrated into hindcast oil spill trajectory modelling, a statistical calculation used to determine likely past conditions.

The West Triton drilling rig at Montara, 2009

OVERVIEW

Asia-Pacific ASA researchers, Dr Brian King and Trevor Gilbert, undertook a study which aimed to document the location of oil released from the Montara oil spill. The data was gathered from real time field and overflight data and satellite observations, and integrated into hindcast oil spill trajectory modelling, a statistical calculation used to determine likely past conditions.

The findings from the study were used to identify areas of oil exposure, as well as areas not exposed to oil, which could act as potential environmental monitoring control sites.

During the response to the Montara spill, extensive daily overflight observations were undertaken by the Australian Maritime Safety Authority (AMSA). This overflight data made it possible to map accurately daily oil slick positions and to interpret observations made by the MODIS (Aqua and Terra) and LandSat (5 and 7) satellites when these were available.

These satellite observations and overflight data were combined into an oil spill model to provide surface oil locations at hourly intervals throughout the entire incident, which lasted from 21 August 2009 until 3 November 2009, when no more surface oil was observed on the Timor Sea.

This data produced more than 2,000 individual snapshots of surface oil locations. This extensive dataset was then combined to produce oil occurrence maps. These were further analysed to determine the duration of all types of surface oil from the spill – from fresh oil to highly weathered waxy residuals.

This approach of combining trajectory modelling, overflight data and satellite images provided the most comprehensive understanding of the spill over time and may be important for determining the likelihood, extent and magnitude of any potential adverse effects from the spill.

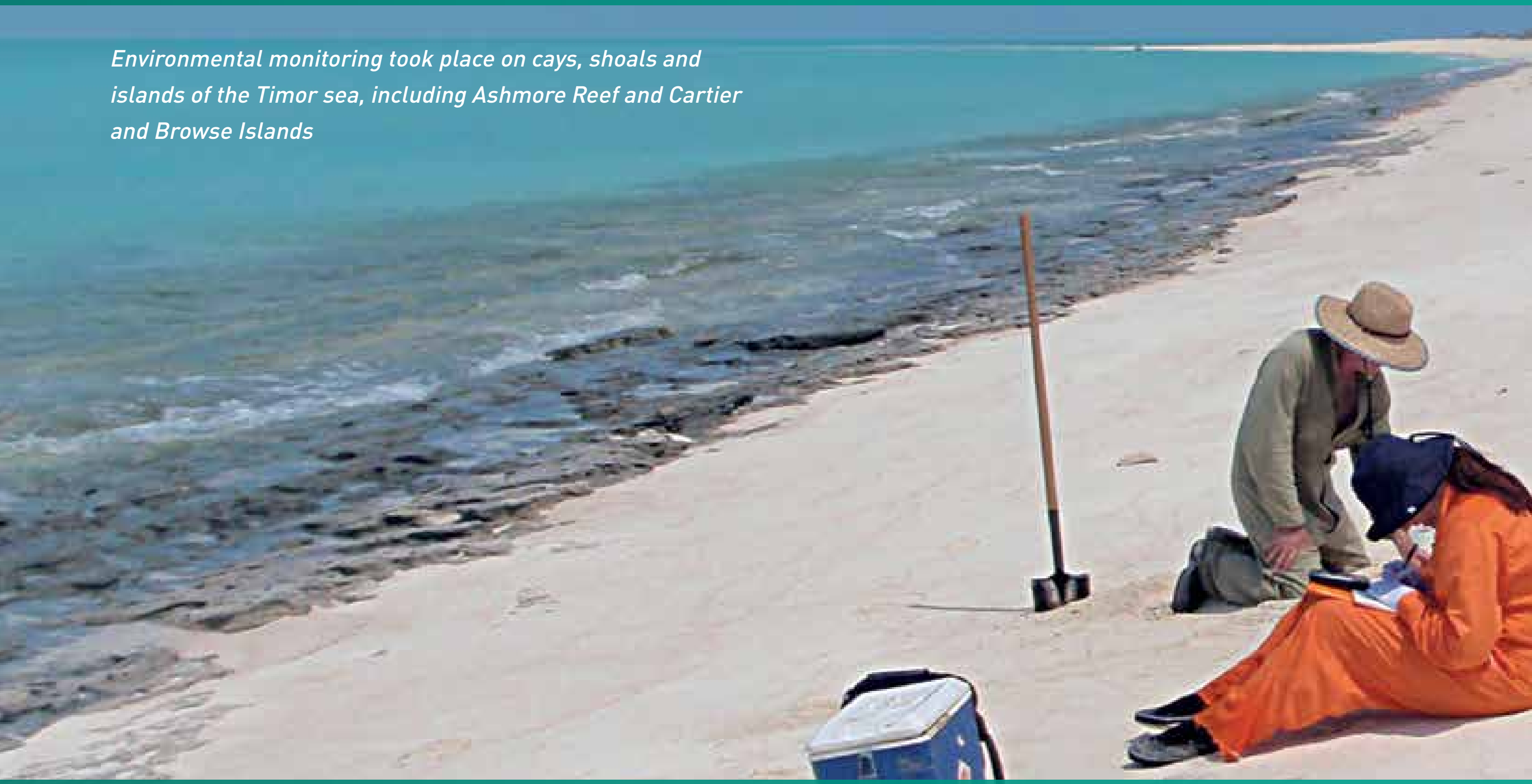
This research helped determine what sites other studies in the Montara Environmental Monitoring Program should use as control sites and which sites it should target as being likely to have been affected by the oil spill.

The West Triton drilling rig at Montara, 2009

KEY RESEARCH FINDINGS

The combined data highlighted the highest occurrence of oil was within a distance of 23 kilometres from the release site and mostly comprised thick and relatively fresh oil. This was also the extent of the AMSA dispersant and recovery operations. On occasions, highly weathered oil returned to this area due to the presence of circular current eddies in the Timor Sea at the time of the spill event.

Beyond the immediate spill area, oil occurrences were generally patchy and more highly weathered, often changing colour. Images of the slick beyond 22.8 kilometres were predominantly sheens or waxy films.



Environmental monitoring took place on cays, shoals and islands of the Timor sea, including Ashmore Reef and Cartier and Browse Islands

Key findings included that:

- no oil reached the Australian mainland or Indonesian coast
- a small quantity of oil entered Indonesian waters, which was reported to relevant Indonesian authorities during response operations.

This study further quantified the area impacted by 99% of the oil from the Montara spill:

- was limited to an approximate radial distance of 82 kilometres from the spill site
- remained almost entirely (98.6%) within Australian Territorial Waters.

The results shown in Figure 1 demonstrate most of the occurrences of surface oil were in the immediate vicinity of Montara. It was typically thick crude orange/brown oil. This was also mostly within the safety exclusion zone set up around Montara due to the associated gas leak from the uncontrolled hydrocarbon flow. The number of occurrences then rapidly declined, due to the ongoing dispersant, recovery and containment operations undertaken by AMSA and the National Response Team.

The closest submerged shoal to Montara was Vulcan Shoal, only 30 kilometres from the spill location. It had the most occurrences of oil pass over it. Barracouta Shoal and Eugene McDermott Shoal also had oil pass over them on occasions, but relatively infrequently.

Most occurrences of surface oil were in the immediate vicinity of Montara. Hydrocarbons found in far-field locations were typically small patches of highly weathered oil surrounded by wax sheets.

The far-field distributions depicted in Figure 1 demonstrated less significant occurrences of oil. The overflight observations indicated any hydrocarbons found in these far-field locations was typically small patches of highly weathered oil surrounded by wax sheets. One confirmed oil stranding on Ashmore Reef was analysed and found to be highly weathered wax residues, indicating the likely characteristics of any occurrences at these distances from Montara.

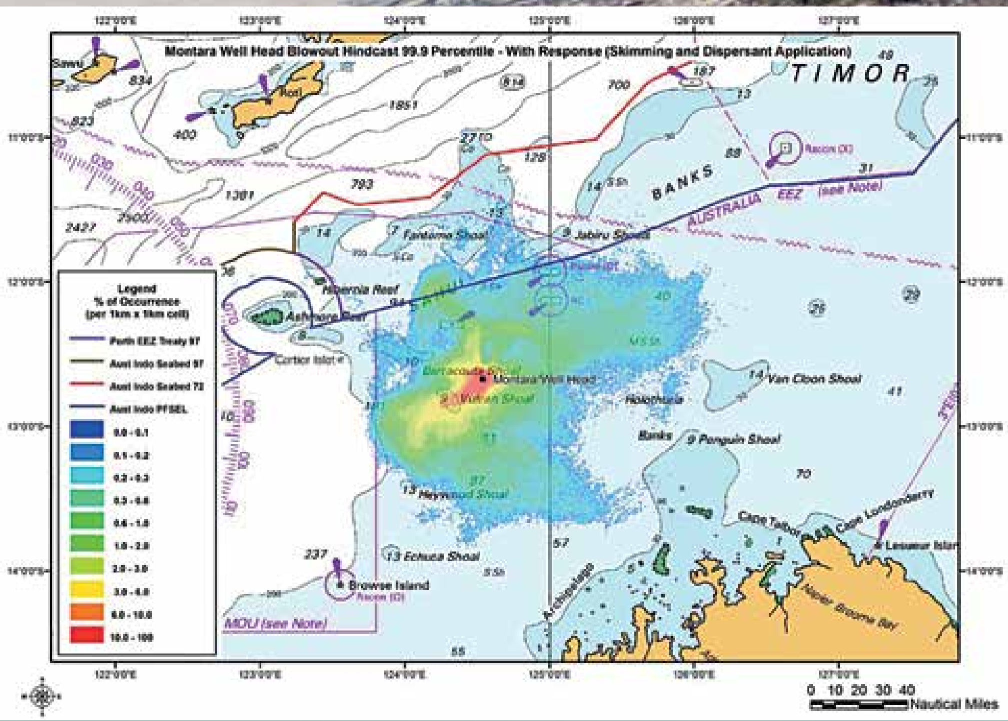


Figure 1: Relative surface oil exposure map representing up to 99.9% of occurrences of visible surface oil associated with the Montara oil spill. It is important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within which isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling

Diagram courtesy of AMSA

Percentile of total counts – number of modelled oil spillets	Number of grid cells hit above nominated level	Square kilometres (number of cells x 1.2 kilometres^2)
90.0 %	231	277 kilometres^2
99.0 %	4708	5,650 kilometres^2
99.9 %	30,338	36,406 kilometres^2
99.99 %	79,628	95,554 kilometres^2

Table 1: Total area of coverage by surface oil, grid cells approximately 0.01° x 0.01° which, in the Timor Sea region, is approximately 1.2 kilometres^2 per grid cell

It is important to note some persistent components of the spilt liquids, particularly its wax content, were likely to continue to exist and may have travelled beyond the extent shown in Figure 2, but at concentrations/coverage which was so low as to be difficult to accurately place or observe from the overflight or satellite images.

The duration of the spill meant some patches of oil eventually drifted into deep waters. Here, fast moving currents associated with the Indonesian Throughflow carried weathered oil patches some significant distances from the source. These were typically small patches which were observed to continue to weather until, ultimately, becoming waxy residues, including solidified waxy residues.

Figure 2 shows the full extent of the estimated extents of the wax residues.

The difference in extents between Figure 1 and Figure 2 (shown as the dark blue band) illustrate the area almost exclusively swept by wax residues, which were mostly in solid form. The dark blue extents in Figure 2 are characterised by one off occurrences with durations of less than two hours in any one location, often associated with fast moving current regimes of the Indonesian Throughflow. The light blue areas indicate extents of limited occurrences with durations of surface oil of less than 20 hours.

The dark blue extents in Figure 2 are characterised by one-off occurrences of highly weathered oil with durations of less than two hours in any one location, often associated with fast moving current regimes

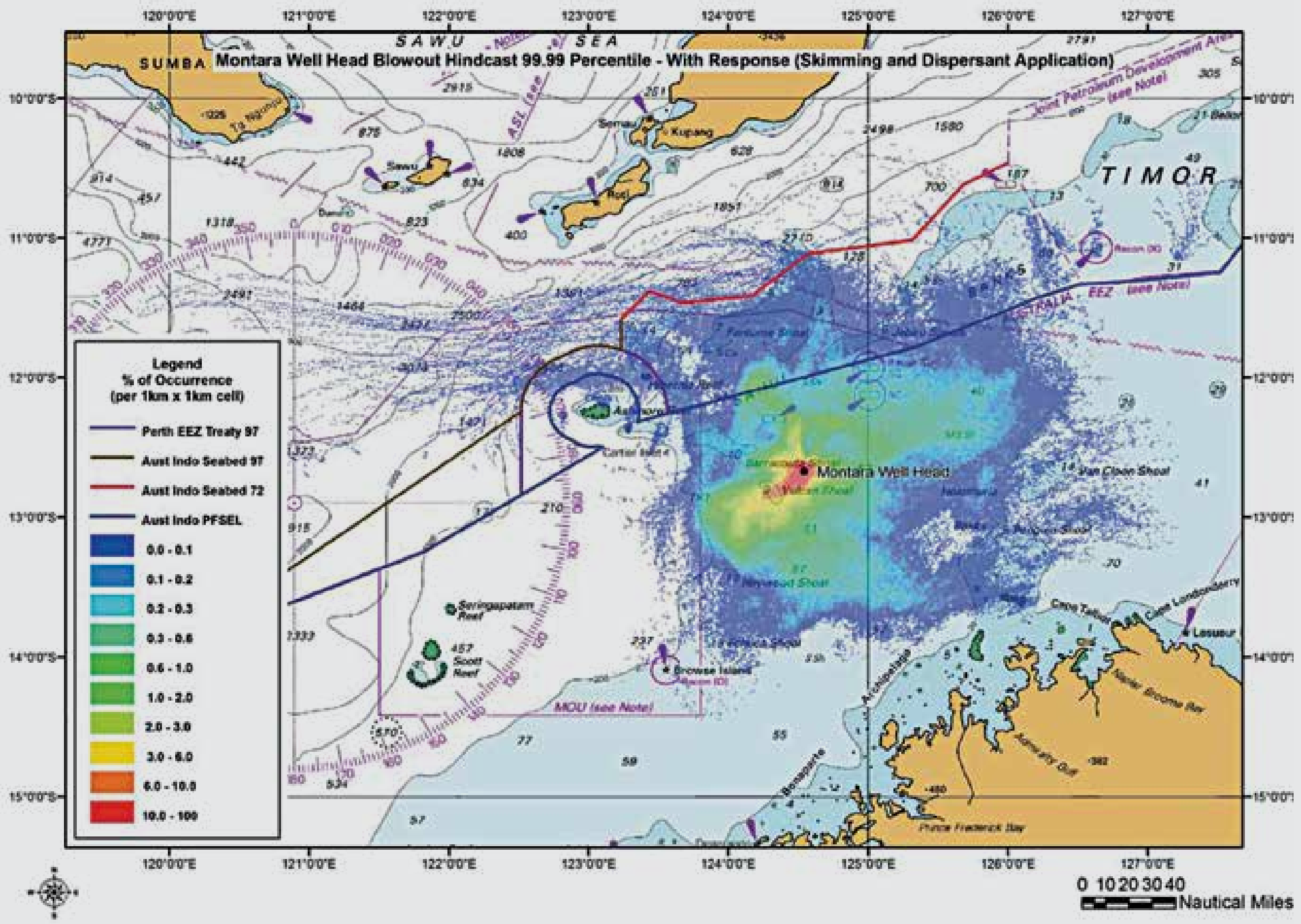


Figure 2: Relative surface oil exposure map representing all known and estimated occurrences of visible surface oil associated with the Montara Incident. It is important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within which isolated patches of oil and wax were observed by aerial or satellite observations and oil spill trajectory modelling

Diagrams supplied courtesy of AMSA

DISCUSSION

The oil spill resulted in reservoir formation water, or water which is released when oil is extracted, gas and hydrocarbon liquids being released above the water surface at temperatures which were likely to have exceeded 80 degrees Celsius.

At these temperatures, condensates were likely to have been in a gaseous form and hydrocarbons impacted the sea surface without their expected condensate composition as partially-weathered crude, which has far less of the lighter volatile hydrocarbons. The outcome of this was the most toxic elements of the hydrocarbons were released into the atmosphere. The temperature of the hydrocarbons contributed to lowering the toxicity of the spill and reduced the volume of hydrocarbons reaching the sea's surface.

Indeed AMSA (2009a, b, c) studies indicated that spilt surface oil did not contain any traces of the volatile aromatic compound BTEX or other light hydrocarbons which would typically be in this crude oil under a normal production operation (which allows for light hydrocarbon condensing).

Overflight observations, by AMSA-directed response personnel, of the slick which developed on the water's surface within the first 24 hours, indicated the spill rate of the crude oil component of the oil spill was initially 400 barrels (64,000 litres) per day as a worst-case estimate.

It is important to note the spill modelling effort during the response was designed to provide search areas for oil and used forecast metocean datasets, which combine meteorological and oceanographic physical data. It assumed worst-case parameters and overestimated possible oil slicks to minimise the chances of losing track of the oil.

For this study, the modelling of slick trajectories was updated every 48 hours to utilise reanalysed metocean data which incorporated field measurements – actual wind and current data rather than forecast data – where possible. For monitoring purposes, the combination of hindcast spill modelling, the daily overflight observations and the use of satellite images, as well as the integration of these three different types of monitoring, ensured the most detailed understanding of the movement and fate of the spilt Montara oil throughout the entire incident.

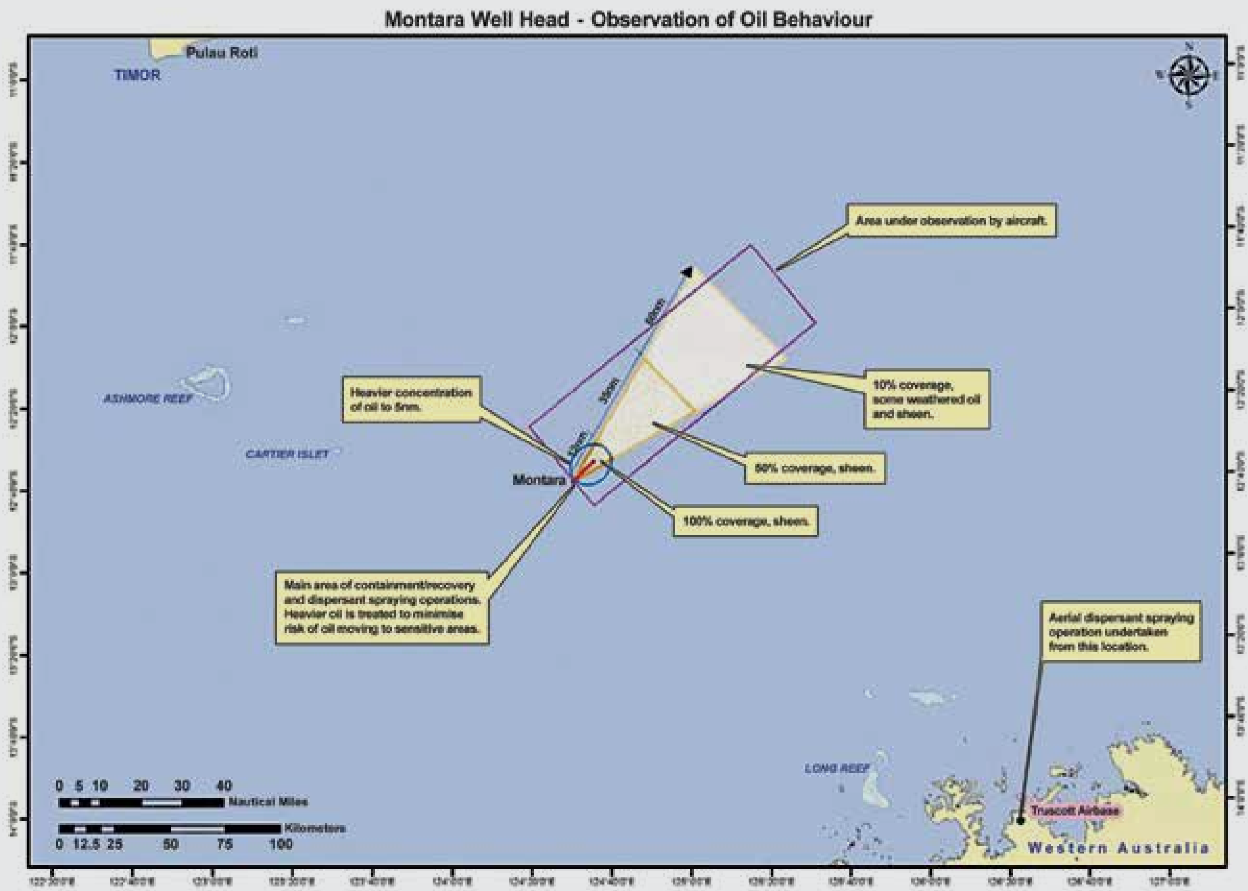


Figure 3: Overflight observation map describing the oil state on 3 September 2009

The most toxic elements of the hydrocarbons were released into the atmosphere, mitigating the toxicity of the spill and reducing the volume of hydrocarbons reaching the sea surface.

Large amounts the oil spill in the Timor Sea were in the form of a sheen, a significant percentage of which was 10 microns or thinner. The sheen is about 100 times lower than what is likely to be considered as being of environmental concern.

Normally, visible oil is detectable at levels ranging from levels of concern when thick and fresh, to well below levels of concern when thin and highly weathered or solidified.

These results from the hindcast model, which included the daily observations and the satellite data, were then loaded into a 0.01° x 0.01° (approximately 1.1 kilometres x 1.1 kilometres) analysis grid which covered the entire Timor Sea. Using specialised software for each hourly interval, the number of times any type of oil, ranging from fresh oil to highly weathered solidified waxy residues, was detected within a grid cell it was recorded. It was then analysed to provide a relative measure of surface oil exposure. The results covered the entire 92 day duration of oil on the water's surface at hourly intervals.

Consequently, the grid cell containing the spill site had the most significant number of occurrences of surface slicks, while grid cells with less than 0.01% of peak occurrences are not shown (see Figure 1 and Figure 2). A logarithmic colour key is used to highlight the relative amount of exposure over the duration of the spill.

Table 1 shows the cumulative areas impacted by oil, wax and sheen over the duration of the spill event as per the modelling. It should be noted the size of the area affected by oil reflects the duration of the spill event, rather than the volume spilt and it indicates the natural dilution mechanisms operating in the Timor Sea.

The methodology of combining the various sources of data not only provided the most robust data possible, it was the first time this approach had been applied to an oil spill. It was subsequently applied to the management of the Macondo oil spill

At the Macondo spill, the amount of oil released in 12 hours equalled the entire cumalative volume of the Montara spill over 74 days, but the oil was spread over an equivalent area. The spill volume at Montara was about 100 times smaller than Macondo.

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The methodology of combining the various sources of data not only provided the most robust data possible, it was the first time this approach had been applied to an oil spill. It was subsequently applied to the management of the Macondo oil spill.

This methodology is now commonly used by oil and gas companies when developing environment plans and oil spill contingency plans, for submission to regulators when seeking to undertake exploration or production work. The innovations developed for this research have positively influenced the industry's preparedness for managing adverse events.

Large amounts of the oil spill in the Timor Sea were in the form of a sheen, a significant percentage of which was 10 microns or thinner. While sheen could be characterised by some observers as visual pollution, it is about 100 times lower than what is likely to be considered as being of environmental concern.

Image supplied courtesy of Curtin University

This discussion was based on the S7.1 Oil fate and effects assessment – spill trajectory analysis research study (led by Dr Brian King and co-authored with Trevor Gilbert). It was enhanced by extensive discussions with Asia-Pacific ASA's Dr King. PTTEP AA is grateful to Dr King and APASA for their contributions to this report.

Oil fate and effects assessment – dispersant oil modelling

Asia-Pacific ASA

Asia-Pacific ASA researchers **Dr Brian King** and **Trevor Gilbert** undertook a study in the latter part of 2009 to model potential concentrations and movement of dispersed oil.

OVERVIEW

The study aimed to gain an understanding of the potential concentrations and movement of dispersed oil in the Timor Sea, which occurred as a result of chemical dispersant spraying operations during the spill response.

The study also aimed to quantify possible environmental exposure of surrounding habitats such as submerged shoals.

The output included a time series of total in-water hydrocarbon concentrations, peak water column concentrations and how these dilute over time, assuming calm conditions. A further purpose of this study was to identify potential study sites and control sites for additional environmental monitoring.

The concentrations of dispersed oil are represented as hydrocarbon concentration in parts per million (ppm) and parts per billion (ppb). The study is based on 50% dispersant effectiveness, which is typical of in-water hydrocarbon concentrations following a chemical dispersant event, and 100% dispersant effectiveness, which is the upper boundary following such an event.

Eleven dispersant events were simulated using three dimensional (3D) modelling. The 11 dispersant scenarios were selected on the basis of:

- those scenarios which would lead to the maximum amount of area affected
- their location. It was important to select dispersant events in different locations and directions around Montara, including those closest to surrounding shoals
- the amount of dispersant applied.

Of these 11 dispersant events, three indicated potential to reach some of the underwater shoals if mixing conditions were at the lower range of what is possible for the Timor Sea and dispersant efficiency was at a maximum of 100%.

Thus, hypothetically, the modelling indicated very low level hydrocarbon concentrations might have been possible under the worst-case assumptions. These would have been in shallow waters, at low concentrations and for short periods of time, due to tidal oscillations:

- two dispersant events resulted in a dispersed oil plume which potentially passed over Barracouta Shoal
- one dispersant event resulted in a dispersed oil plume which potentially passed over Goeree Shoal (refer to Table 1, page 96).

Dispersants are applied to mitigate the negative impact of an oil spill by causing the mixing of the oil through a greater amount of the water column than would otherwise occur. The dispersant process reduces the concentration of oil within water, mitigating its potential impact.

The response to the spill was undertaken under the direction of the Australian Maritime Safety Authority (AMSA) and included both containment and recovery and dispersant application strategies.

A number of small sub-tidal sea mounts or pinnacles occur nearby to Montara. The nearest tidally exposed islands and reefs occur some 90 kilometres to the west at Cartier Island, Ashmore Reef and Hibernia Reef. Cartier Island Marine Reserve and Ashmore Reef National Nature Reserve are both part of the National Representative System of Marine Protected Areas.

The nearest sea mount is Vulcan Shoal, located 30 kilometres to the south west of Montara. Other nearby sea mounts includes Goeree, Barracouta and Eugene McDermott Shoals.

Image supplied courtesy of AIMS

KEY RESEARCH FINDINGS

3D modelling indicated the maximum concentration of hydrocarbons in the water column at any depth at any time following the dispersant events studied was 3.48ppm. This concentration was reached immediately after the dispersant event on 1 October 2009. It was concentrated within the top metre of the water column, within 23 kilometres of Montara, as part of AMSA-directed response.

The 3D modelling of the dispersant events also indicated the Australian Government-approved chemical dispersants caused elevations in hydrocarbon concentrations in the water column, mostly within the first metre of the water column. The concentration of hydrocarbons reduced quickly with time, depth and distance from the dispersant application site.

The six types of dispersant used – Slickgone NS, Slickgone LTSW, Ardrox 6120, Tergo R40, Corexit 9500 and Corexit 9527 – were all prior approved for use within Australian waters, having passed laboratory acute toxicity testing requirements applied under the National Plan arrangements (AMSA, 2010).If found at depths of over one metre, the dispersed oil plume would reduce below concentrations of 0.010 ppm or ten ppb at a distance of 70 kilometres from the dispersant application site, indicating a localised concentration of hydrocarbons centred around the spill site.

Study results further indicated that four days after the dispersant was applied, hydrocarbon concentrations in the water column were found to be below one ppm in all the dispersant events modelled and analysed. An average concentration was calculated over the four days (96 hours) after the dispersant event. All the dispersant events had, as four day averages, less than one ppm of hydrocarbon concentrations.

Three dispersant events created elevated concentrations of hydrocarbons over submerged shoals. The 3D modelling demonstrated the concentrations reached at the shoals were very low, at less than 0.010 ppm or 10 ppb, and for durations of less than 18 hours.

For the 11 dispersant events, hydrocarbon concentrations in the water column for the realistic scenarios of 50% dispersant effectiveness ranged from maximum in-water elevations of 0.46 ppm to 2.93 ppm, as well as average 96 hour concentrations between 0.16 ppm to 0.56 ppm (refer to Table 2, page 97).

Hydrocarbon concentrations in the water column for worst case scenarios, assuming 100% dispersant effectiveness, due to these 11 dispersant events ranged from maximum in-water elevations of 0.98 ppm to 3.48 ppm, as well as average 96 hour concentrations of 0.37 ppm to 0.90 ppm (refer to Table 3, page 97).

The concentration of hydrocarbons in the water drops rapidly due to natural dilution, falling below 0.17 ppm with 50% dispersant effectiveness, (refer to Table 2, page 97) or 0.31 ppm for 100% dispersant effectiveness (refer to Table 3, page 97) within four days of all the dispersant events studied.

After nine days, the concentration of hydrocarbons in the water column approaches concentrations of 0.08 ppm and below in all of the dispersant events studied (refer to Table 2 and Table 3, page 97) even when assuming low mixing conditions prevailing over this length of time.

The modelling also indicated in some cases when a natural dispersion event, such as high winds of greater than ten knots, could cause non-chemically treated surface oil to enter and mix with the water column:

- this often caused the concentrations of hydrocarbons in the water column to rise above the levels caused by the chemical dispersion event alone
- these short term concentrations were formed near the surface following a moderate wind
- these natural dispersion events were outside of the scope of this study.

Crude oil was released into the environment as part of the Montara oil spill. Liquids were released above the water surface at temperatures expected to have exceeded 80 degrees Celsius. At these temperatures it is estimated condensates were gaseous and the liquid which impacted the sea surface was without its expected condensate composition, essentially as pre-weathered crude oil.

The persistent components of the crude oil, which are nearly all the components of the hydrocarbons, except for the gaseous ones, then fell to the ocean surface from the structures on-site, mostly via storm water drains.

The temperature of the hydrocarbons contributed to lowering the toxicity of the spill and reducing the volume of hydrocarbons reaching the sea's surface.

Many of the lighter volatile hydrocarbons became gaseous.

The outcome was the most toxic elements of the hydrocarbons were released into the atmosphere. The temperature of the hydrocarbons contributed to lowering the toxicity of the spill and reducing the volume of hydrocarbons reaching the sea's surface.

Overflight observations by AMSA-directed response personnel of the slick, which developed on the water's surface within the first 24 hours, indicated the spill rate of the crude oil component of the oil spill was initially 400 barrels (64,000 litres) per day as a worst-case estimate.

The crude oil continued to be released until the well was brought under control on 3 November 2009.

Daily overflight observations, computer simulations of slick trajectories and the use of satellite images were undertaken by AMSA for planning and operational monitoring purposes throughout the incident. The surveillance and modelling indicated surface oil was not detectable in the Timor Sea after 15 November 2009.

During the response operations a number of monitoring activities were undertaken to monitor the dispersant operations in the water column (AMSA 2009). AMSA recommends "for environmental effects assessment purposes, the distribution and concentration of dispersed oil should be modelled using available 3D models".

The results of this 3D modelling study are in line with the laboratory results from the AMSA 02.03 (AMSA 2009) report. The average and maximum peak concentrations fall within the range that was analysed in the laboratory, where total petroleum hydrocarbon levels reached a high of 3.5 ppm at a depth of one metre.

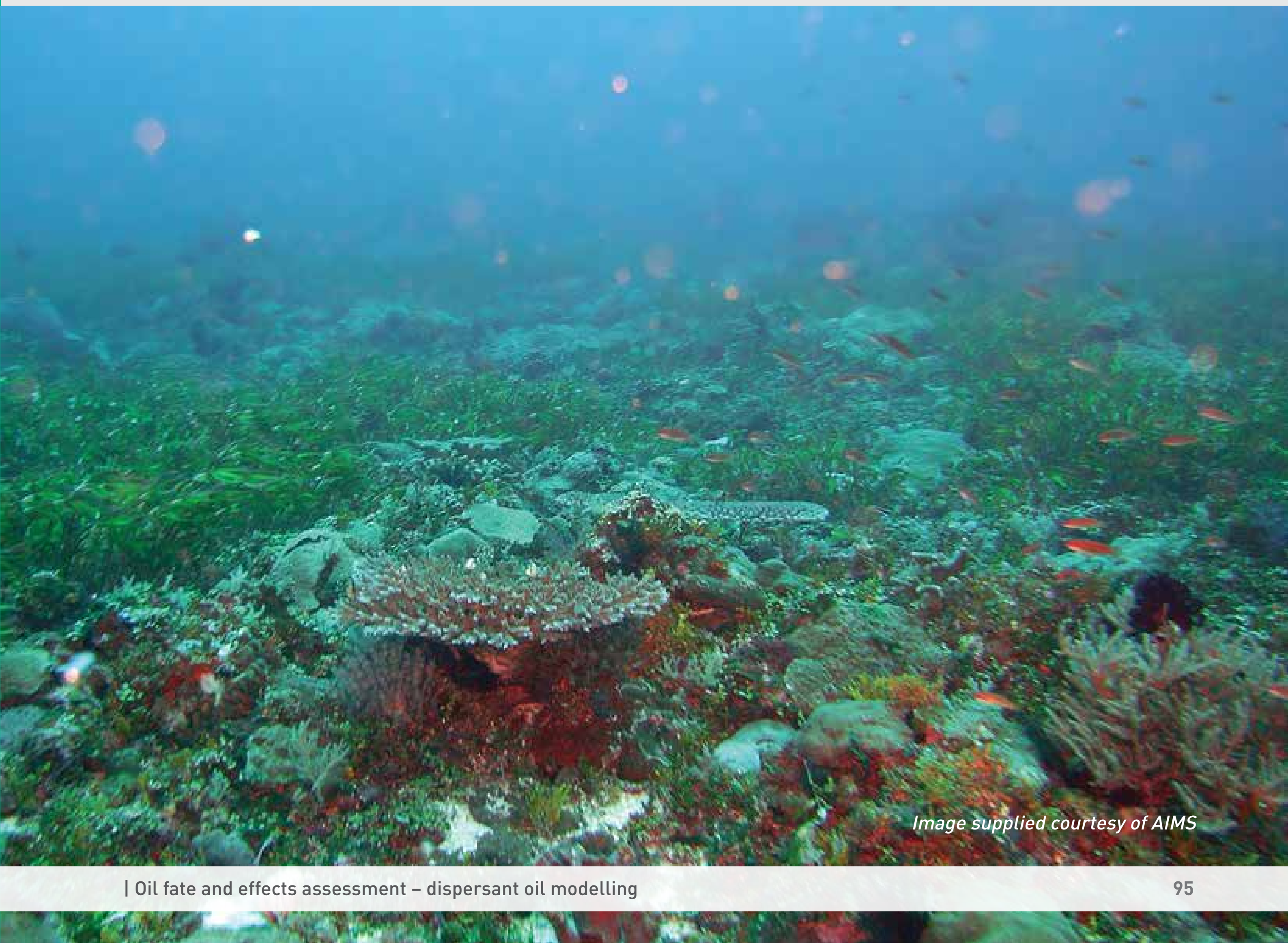

Image supplied courtesy of AIMS

...hydrocarbon concentrations in the water column caused by the chemical dispersant were considered low in comparison to hydrocarbon concentrations in the water column caused by natural dispersion events.

The maximum hydrocarbon concentrations found with 3D modelling were 3.48 ppm. This peak event was due to the lower advection and mixing associated with neap tides, when the difference between the low and high tides is the smallest, which occurred at this time.

The duration of exposure is also consistent with an AMSA (AMSA 2009) report which states "the chemical analysis of sampled waters suggest that concentrations of dispersed oil below treated slicks are low (less than 5 ppm) and are rapidly diluted over depth and time (to less than 1 ppm)".

Even in the worst case scenario of 100% dispersant effectiveness, the hydrocarbon concentrations in the water column caused by the chemical dispersant were considered to be low in comparison to hydrocarbon concentrations in the water column caused by natural dispersion events. It was also low compared with the overboard discharge clean water specifications of 30 mg/L daily oil content (Petroleum (Submerged Lands) (Management of Environment) Regulation 1999).

The application of chemical dispersants to mitigate the impact of hydrocarbons on the environment was proven to be an effective response:

- without dispersants, which break up the hydrocarbon and facilitate it entering the water column, the hydrocarbons would have dispersed across only the *surface* of the Timor Sea, potentially negatively impacting on a larger area than actually occurred
- with dispersants, the hydrocarbons enter the water column itself and thus can meld more quickly, and with less impact, into the environment.

Table 1: Hydrocarbon exposure to shoals

Location	Dispersant application date	Date and time of pass over shoal	Duration of pass over shoal	Maximum hydrocarbon concentration of pass (ppm)
Barracouta Shoal	01/09/2009	08/09/2009 02:00 am	2 hrs	0.001
		08/09/2009 08:00 pm	16 hrs	0.048
		09/09/2009 06:00 pm	6 hrs	0.025
Barracouta Shoal	02/09/2009	07/09/2009 10:00 pm	2 hrs	0.015
		08/09/2009 06:00 am	14 hrs	0.099
Goeree Shoal	17/09/2009	21/09/2009 12:00 am	12 hrs	0.024

Table 2: Realistic scenario - 50% dispersant effectiveness (all numbers in ppm)

Date	Concentration after 4 days	Concentration after 9 days	96 hr Average concentration	Maximum concentration
24 August 2009	0.17	0.05	0.50	1.66
25 August 2009	0.15	0.05	0.45	1.16
30 August 2009	0.14	0.04	0.54	1.53
01 September 2009	*0.03*	*0.04**	*0.16*	*0.78*
02 September 2009	*0.08*	*0.05*	*0.33*	*1.1*
17 September 2009	*0.12*	*0.11#*	*0.23*	*0.46*
24 September 2009	0.03	0.12*	0.19	1.03
01 October 2009	0.17	0.06	0.56	1.72
06 October 2009	0.10	0.06	0.54	2.93
08 October 2009	0.14	0.3*	0.28	1.18
10 October 2009	0.17	0.06	0.55	1.56

Table 3: Realistic scenario - 50% dispersant effectiveness (all numbers in ppm)

Date	Concentration after 4 days	Concentration after 9 days	96 hr Average concentration	Maximum concentration
24 August 2009	0.16	0.05	0.57	2.28
25 August 2009	0.27	0.06	0.71	2.32
30 August 2009	0.14	0.06	0.53	2.70
01 September 2009	*0.09*	*0.06**	*0.37*	*1.62*
02 September 2009	*0.15*	*0.08*	*0.59*	*2.01*
17 September 2009	*0.31*	*0.26#*	*0.53*	*0.98*
24 September 2009	0.04	0.07*	0.37	2.07
01 October 2009	0.21	0.08	0.77	3.48
06 October 2009	0.20	0.06	0.63	2.96
08 October 2009	0.14	0.53*	0.37	1.26
10 October 2009	0.30	0.12	0.90	1.71

* *Indicates that this concentration is attributed to a natural dispersion event (high winds above 10 knots).*

\# *Indicates that this scenario could only be run for five days after the dispersant event as high winds produced unrealistically high in water concentrations after five days, which is not indicative of the dispersion which would have occurred due to dispersant application alone.*

Entries in italics indicate the dispersed oil made contact with an underwater shoal in that scenario.

This discussion was based on the S7.1 Oil fate and effects assessment – spill trajectory analysis research study (led by Dr Brian King and co-authored with Trevor Gilbert), but was enhanced by extensive discussions with Asia-Pacific ASA's Dr King. PTTEP AA is grateful to Dr King and APASA for their contributions to this report.

Red footed booby in flight

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An example of the dugong species

GLOSSARY OF TERMS

Abiotic	Non-living chemical and physical factors in the environment
AIMS	Australian Institute of Marine Science
ALARA	As low as reasonably achievable
AMSA	Australian Maritime Safety Authority
ANZECC	Australian and New Zealand Environment Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
Ascidians	Commonly known as sea squirts). They are a sac-like marine invertebrate filter feeder
Bathymetry	The study of the underwater depth of lakes or ocean floors
Benthic	The ecological region at the lowest level of a body of water
Biliary	Of or relating to bile or the bile duct
Bilirubin	An orange-yellow pigment formed in the liver
Bimodal distribution	A continuous probability distribution with two different modes
Biomarkers	Biochemical markers
Biota	The animal and plant life of a particular region, habitat, or geological period
Biotic	Living chemical and physical factors in the environment
BTEX	A volatile aromatic compound; stands for benzene, toluene, ethylbenzene, and xylenes which are chemical compounds found in BTEX
Carcinogenic	Having the potential to cause cancer
Cay	A small, low-elevation, sandy island formed on the surface of a coral reef
Chromatogram	A visible record (such as a series of coloured bands, or a graph) showing the result of separation of the components of a mixture by chromatography
Demersal fish	Fish that live and feed on or near the bottom of seas or lakes
Depurate	To purify and remove impurities from something
Detritivores	Organisms which gain nutrients by consuming detritus
Diploptene	The biomarker for sulphate-reducing bacteria which are known to degrade hydrocarbons
DOV	Diver operated stereo video
Ecotoxicologists	Scientists who study the impact of chemicals on biological organisms
Emergent reef	Reefs which have been exposed by the sea due to a relative fall in sea levels
Endogenous	Substances which originate from within an organism, tissue, or cell
EPA	Environmental Protection Authority
EPBC	Environment Protection and Biodiversity Conservation Act 1999
Gametogenesis	Cell division which occurs as part of fertilisation and spawning
GBRMP	Great Barrier Reef Marine Park

Gradient Analysis	An analysis method involving the abundance of species in an environment and relating it to various environmental gradients. These gradients are variables which are important to the environment and include temperature, water availability, light and soil nutrients
Gravid	Pregnant; carrying eggs or young
GSI	Gonado-somatic index
Herbivore	Plant eater
Hermaphroditism	The presence of a male and a female gonad in the same individual
Hindcast	Numerical modelling used for analysing data
Histological	Studying the microscopic anatomy of cells and tissues
Histological examination	The study of a tissue specimen by staining and then examining it
Hydrocarbon fluxes	The rate at which hydrocarbons migrate to the surface
Hydrodynamics	The movement of water in the vicinity
Intersex gonads	The presence of a female reproductive cell in a testis
Invertebrate	An animal lacking a backbone
Light oil	Lighter fuel oils distilled off during the refining process
Lower advection	The horizontal transfer of a property such as heat, caused by air movement
LSI	Liver somatic index
Megafauna	Large or giant animals
Meso scale region	A region used to describe an area of approximately one km2 to 10,000 km2
Metabolite	The intermediates and products of metabolism
Metocean	A combination of meteorological and oceanographic physical environments
MLs	Maximum levels
Multivariate analyses	The observation and analysis of more than one statistical outcome variable
Mutagenic	Capable of inducing mutation
NDSMF	Northern Demersal Scalefish Managed Fishery
Olfactory	Of, or relating to the sense of smell
Ontogenetic migrations	Organism development-driven
Oocytes	Cells involved in the reproductive process
PAHs	Polycyclic aromatic hydrocarbons
Peak water column	A conceptual column of water from surface to bottom sediments
Pelagic fish	Fish which live near the surface or in the water column of coastal, ocean and lake waters
Photosynthetic	The process in green plants and certain other organisms by which carbohydrates are synthesised from carbon dioxide and water using light as an energy source
Phototrophic species	Organisms which capture light to acquire energy
Piscivores	Carnivorous animal which primarily eats fish
Planktivores	Aquatic organisms which feed on plankton

Plastrons	The virtually flat portion of the shell structure of an organism such as a turtle
PPB	Parts per billion
PPM	Parts per million
Pre-weathered crude oil	Crude petroleum which has lost much of its volatile components as a result of natural causes during the storage and handling stages
Primary producers	Organisms in an ecosystem that produce biomass from inorganic compounds and as a result, are the first link in all food chains
Produced formation water	Water generated during the process of oil and gas extraction from the subsurface. This water includes that which was in the reservoir to begin with, as well as water which has been injected to help force the oil to the surface.
Protandryous hermaphrodites	Starting life as males before switching to females
Protogynous hermaphrodites	Starting life as females before switching to males
Reef	A rock, coral or sand ridge located just above or below the sea surface
Reservoir formation water	Water which occurs as part of the oil extraction process
Rhizomes	A modified subterranean stem of a plant
Rudimentary hermaphroditism	Having both male and female gonadal tissue in early life stages
Rugosity variables	The variables which affect the amount of habitat available as settlement for benthic organisms, as well as the amount of shelter and foraging space which mobile organisms have
SDH	Sorbitol dehydrogenase
SE	Standard error. This is a term meaning the standard deviation of the sampling distribution of a statistic
SEWPaC	Federal Government Department of Sustainability, Environment, Water, Population and Communities
Shoal	A large group of fish which swim together; or a linear landform which is typically long and narrow
Spermatagonia	Cells which are intermediaries in the production of sperm
Sterane	Any of a class of saturated polycyclic hydrocarbons which are found in crude oils and are derived from the sterols of ancient organisms
Submerged reef	Reefs which have been inundated by the sea due to a relative rise in sea levels
Thermoclines	Layers of water acting as a temperature 'blanket' between different depths
Triterpane	Any of a group of terpenes found in plant gums and resins
UVC	Underwater visual census
Water column	A figurative column of water which describes the area from the top of the sea to the sea floor
Xenobiotic	A chemical which is found in an organism but which is not normally produced or expected to be present in it
Zooplankton	The animal component of plankton consisting mainly of small crustaceans and fish larvae
3D	Three dimensional

Little egret

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