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CONCLUSION

The MV *Rena* shipwreck: time-critical scientific response and environmental legacies

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ABSTRACT
The sinking of the MV *Rena* on Astrolabe Reef (Otaiti) in the Bay of Plenty, New Zealand, resulted in the release of oil and ship debris, including dangerous goods carried as cargo. Two key questions of concern to the public and environmental managers were posed immediately: what was the impact of the *Rena* oil spill and how long would it take for the marine environment to recover? The research that began immediately after the ship grounded provided answers, as documented in this special issue.

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The contaminants attributed to the MV *Rena* were tracked in real time and their effects assessed from extensive field monitoring across the region's marine habitats. The science coalition formed to assess environmental damage and recovery provided multidisciplinary skills in ecology, chemistry, physiology and toxicology to deal with the many faceted impacts as they unfolded. Oil spills themselves are rarely 'simple' but the effects become far more complicated when a toxic brew of oil mixes with a wide range of contaminants as they spill from a ship. The studies presented in this volume show there were both acute and chronic effects on various marine species. Surprisingly, there were relatively few lasting effects of the oil itself on the integrity of coastal habitats or species. Legacy effects are now largely restricted to the area around Astrolabe Reef, where the remnants of the ship and contaminants remain. We present a summary of the lessons learned from the *Rena* wreck and end with a recommendation that environmental scientists be part of the first-response team for future shipwrecks.

Scope and focus

In the aftermath of the sinking of the MV *Rena* there were two key questions of concern to Bay of Plenty public, iwi, environmental managers and commercial stakeholders (Schiel et al. 2016a). What was the impact of the *Rena* oil spill? How long would it take for the marine environment to recover? This special issue has drawn largely from the work of Te Māori Moana, the research partnership comprised of tertiary institutes and iwi,

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established after the *Rena* grounded on 5 October 2011. In a move that can be considered a precedent for New Zealand, and indeed is unique for maritime disasters anywhere, the Minister for the Environment mandated that the mauri ('life force that binds all things' [Love et al. 1993; Roberts et al. 1995; Harmsworth & Awatere 2013]) of the environment needed to be recognised and the effects of *Rena* ascertained so that a return to a 'pre-*Rena*' state could be achieved (Ministry for the Environment 2011). The research programme was designed in consultation and collaboration with Bay of Plenty iwi to establish a comprehensive review of environmental responses to *Rena* contaminants (Battershill et al. 2013). The papers presented in this special issue focus on the science underpinning: (1) the operational and social responses to the oil spill and loss of contaminants from the shipwreck; (2) the fate of contaminants in the environment; and (3) the ecotoxicological effects of *Rena*-derived contaminants and oil dispersants on native marine biota. Here we offer some general conclusions and make some recommendations for responses to future shipwrecks.

The impacts

Visualisations of disasters are usually evocative and those relating to oil spills tend to elicit strong reactions. The *Rena* oil spill had a powerful effect on the local community (Lockwood 2016). Vivid images of the thick heavy fuel oil (HFO) from the grounded vessel washing on to the Bay of Plenty coast, and coating rocks, beaches and birds, portrayed the severity of the situation. This crisis had a significant cultural impact on the lives of many Māori (the indigenous people of New Zealand) who place great importance on mauri (Marsden & Henare 1992). The anger and frustration of local people as they came to terms with the *Rena* incident led to growing public demand to be involved in the response effort. Responding to public pressure, Maritime New Zealand (MNZ) incorporated volunteers into its official response plan. Volunteering, much of it self-organised, became a major component of the clean-up, and was ultimately hailed as a success; it was described as the first-ever effective volunteer response following an oil spill (Gillespie 2011). The severity and longevity of the ecological impacts of the oil on the Bay of Plenty coastline were without doubt reduced by the actions of volunteers, mainly because the 'hands and knees' clean-up operation largely kept heavy machinery off beaches and prevented oil from being driven deep into sediments (AMSA 2009). Perhaps as importantly, it made the community feel as if they were making a meaningful contribution to the recovery operation (Sargisson et al. 2012; Lockwood 2016).

The long-term ecological impacts of the *Rena* incident are probably less severe than the perceptions of impacts by the people of the Bay of Plenty. Although a major maritime disaster for New Zealand (Ministry for the Environment 2011), the *Rena* oil spill was relatively minor by world standards in terms of the volume of oil lost to sea (Paine et al. 1996; Albaiges et al. 2006; Griffiths 2012). Animal casualties, mainly birds, were recorded (Gartrell et al. 2013) but there was no evidence of severe adverse ecosystem-level responses such as those seen in many major oil spills (Jewett et al. 2002). On rocky intertidal reefs, the coverage of oil was initially patchy and decreased by c. 90% over 5 months due to natural weathering processes. While there were immediate effects of oil fouling on some sessile organisms and associated fauna, no ecological effects on any rocky intertidal community were detectable a few months after the spill (Schiel et al. 2016b).

On coastal beaches—the habitat most visibly affected by *Rena* oil—there was no evidence of mass mortality of intertidal infauna either during or following the oil spill. For *Paphies subtriangulata*, an edible endemic surf clam, oil products (polycyclic aromatic hydrocarbons [PAHs]) were taken up quickly and then rapidly depurated with seemingly little adverse effect (Ross et al. 2016a). While the resilience of soft sediment communities was surprising, it may be explained variously by the effectiveness of the oil removal (de Lange et al. 2016), through behavioural adaptations of the affected organisms (reduced feeding activity or deeper burrowing), the weathering of the more volatile components of *Rena* oil prior to arrival on the coast, or a resilience to oil evolved through regular exposure to vessel-, vehicle- and industry-derived hydrocarbons delivered to coastal waters by stormwater and pollution events (Brown & Peake 2006).

On Astrolabe Reef—the site of the grounding—the environment has not fared quite so well. Analyses of trace metals, PAHs and organotins in sediments, the water column and in biota have indicated significant but localised contamination (Ross et al. 2016b; Dempsey et al. 2016). More than 3 years after the grounding, *Rena*-derived PAHs, copper, tin and zinc are present in reef sediments above Australia and New Zealand Environment and Conservation Council (ANZECC) guideline concentrations. Copper and other metals (iron, aluminium, zinc and manganese) are also present in the water column overlying the debris field at concentrations that are elevated relative to reference locations (Dempsey et al. 2016). Of continuing concern is the presence of tributyltin (TBT), a constituent of anti-fouling paint banned in 2008 (IMO 2001), in sediments over much of Astrolabe Reef and in biota across several trophic levels (Ross et al. 2016b). Body burdens of TBT lower than those recorded in Astrolabe Reef biota are known to have caused adverse physiological effects in organisms elsewhere (Evans 1999; Sousa et al. 2014). Despite the presence of these contaminants on the reef, ecological effects are not currently apparent outside the ship's debris field. Within the debris field, physical disturbances through scouring and smothering by the wreck and associated container debris are responsible for localised losses of benthic organisms. The contribution of chemical contamination to these ecological changes is unknown. Now that the salvage is nearing completion and much of the wreck and debris have been recovered from depths less than 30 m, recolonisation of denuded rocky substrata by macro-algae is occurring.

The consequences of oil and other contaminants on the ecology of the water column are not well understood. It was not possible to conduct in situ monitoring during the periods where oil was being released from the stricken vessel or in the two instances when the oil dispersant Corexit 9500 was being used to combat the oil slick at sea (Maritime New Zealand 2013). However, ecotoxicological assays were done a posteriori to examine lethal and sub-lethal effects of the water-accommodated fraction of HFO and Corexit 9500 on adult and larval fish and rock lobster (Muncaster et al. 2016; Webby & Ling 2016). These assays indicated that the effects of HFO on its own are likely to have been relatively minor for adult fishes and crustaceans (Webby & Ling 2016). In contrast, for larval fish, ecologically relevant PAH concentrations caused some morbidity and developmental abnormalities (Muncaster et al. 2016). For all organisms and life stages examined, the addition of Corexit 9500 increased the uptake and toxicity of PAHs, leading to greater mortality and amplified sub-lethal effects.

The legacy

The initial environmental concerns of stakeholders and the public were largely centred on a feared legacy of oil pollution and long-term losses of biodiversity, fisheries and harvested shellfish, as well as losses to the local economy, as experienced after the *Exxon Valdez* oil spill in Alaska in 1989 (Jewett et al. 2002). However, it is now clear that the legacy of the *Rena* is actually not the oil but the ship and its cargo. The Bay of Plenty coastline recovered quickly from its coat of HFO. The speed with which beached oil was removed and the use of manpower rather than heavy machinery, which has the potential to drive oil deep into the sand (AMSA 2009), played a significant part in this positive outcome. Three years after the grounding there is little evidence of *Rena*-derived oil on the Bay of Plenty coastline (de Lange et al. 2016). In fact, the main evidence that the grounding ever occurred is the occasional appearance of plastic beads, seemingly innocuous items from the ship's cargo that have turned out to be one of the more widespread and persistent reminders of the incident.

On Astrolabe Reef, although PAHs are still present above ambient concentrations, the causes of long-term environmental effects will be components of the ship and its cargo that did not register as a concern until many months after the ship sank. For cargo ships, the range of potential pollutants is large and includes commercial and industrial chemicals and materials, raw minerals, oils, paints, manufactured goods, agricultural and horticultural produce, and personal belongings. Metals are present in almost every component of a ship's structure (Dimitrakakis et al. 2014). Many of these prospective contaminants have the potential to persist in the environment for much longer than oil. The two *Rena*-derived contaminants thought most likely to cause long-lasting effects on Astrolabe Reef are copper and TBT. The *Rena* was transporting a container carrying 21 t of copper clove (granulated copper wire fragments). When the hull of the ship ruptured, the copper was deposited on the north-eastern slope of Astrolabe Reef at a depth of c. 30–45 m. Despite the considerable efforts of the ship's salvors, the copper could be only partially recovered with much of it presently lying beneath the hull of the sunken stern (TMC Marine 2015). If the copper remains where it is, any ecological effects are likely to be localised. However, future dispersal of the copper clove over other sections of the reef could result in additional adverse ecological effects.

The other contaminant of particular concern is TBT, which has consistently been recorded in sediments and biota across Astrolabe Reef (Ross et al. 2016b). TBT is a potent and persistent toxin, considered to be one of the most effective marine anti-foulants ever used (Evans 1999; Sousa et al. 2014). TBT was banned globally in 2008 (IMO 2001) due to extensive contamination of the marine environment and its extreme toxicity to a wide range of aquatic organisms at low concentrations (Fent 2006; Sonak et al. 2009). Despite the *Rena* having been certified as TBT free, TBT-based anti-fouling several layers beneath the *Rena*'s most recent coat of paint was scraped from the hull during the initial grounding, through subsequent wreck movements and, to a lesser extent, by the act of salvaging the hull. TBT is present in sediments on and adjacent to Astrolabe Reef at concentrations likely to have adverse effects (Ross et al. 2016b). It is also present in biota including whelks, urchins and fishes. However, adverse ecological effects, such as imposex, have not yet been recorded (Barter & Jones 2015). Whether problems arise in the future as a consequence of these contaminants remains to be seen.

Based on the findings presented in this volume, the concerns of the public around a major environmental disaster can be largely put to rest. However, it appears to be somewhat fortuitous that the legacy of the *Rena* is fairly localised contamination at the site of the grounding with little if any lasting impact on coastal ecosystems. The urgent entry of salvage vessels into New Zealand waters from overseas posed a risk of biological invasion, with the potential for effects more ecologically significant, widespread and longer-lasting than any oil spill. Two of these vessels, a cargo barge and tug, had well-developed biofouling assemblages that included non-indigenous species new to New Zealand (Smith et al. 2016): the mangrove crabs, *Metopograpsus latifrons* and *M. frontalis*; the bivalves, *Patro australis* and *Neotrapezium sublaevigatum*; and the red alga *Grateloupia* sp. *filicina*-type. The vessels were treated 6 weeks after their arrival in Tauranga and active surveillance carried out since has recorded no sightings of these unwanted organisms.

Lessons learned

Although the *Rena* shipwreck did not turn out to be the major maritime disaster it was predicted to be, it nevertheless provides an opportunity to improve the way in which we respond to oil spills and marine contamination events. Documenting and gaining an understanding of the ecological, cultural and social recovery from this incident provides insight into operational responses that will aid with future shipwrecks. The main lessons learned from the *Rena* incident relate to the need for timely input by environmental scientists with relevant expertise to review likely effects of oil and other contaminants, and also the necessity of their engagement with statutory responders (MNZ and regional agencies). Addressing the concept of mauri is suggested to provide a useful and unifying synthesis across otherwise frequently disparate monitoring and research pursuits associated with assessing environmental impacts from major pollution events. So what have we learned? How will these lessons inform future disaster management?

Lesson 1. Quick response and baseline data are useful!

The value of having access to long-term data sets has been demonstrated in this research programme. The existence of 30+ years of monitoring data for coastal and estuarine ecosystems provided by the Bay of Plenty Regional Council combined with a long-term rocky reef research programme—part of a national biodiversity investigation (e.g. Blanchette et al. 2009)—provided a robust, scientifically defensible background to the pre-*Rena* state for many relevant habitats in the region. Furthermore, it was fortunate that key researchers were based at a coastal research laboratory in Tauranga, near the wreck site, and were able to quickly do baseline sampling to fill in knowledge gaps after the grounding but before oil was evident. The assembled background information facilitated the identification of vulnerable habitats, deployment of oil slick containment ordinance, and rapid planning of monitoring programmes and protocols. Baseline data also provided the necessary backdrop against which ecotoxicological effects and environmental impacts and recovery could be measured. A crucial correlate of these initial responses was that environmental scientists were part of the response and were able to explain in public meetings what the immediate effects were and what was being done to lessen them. An achievable priority for future preparedness should be the collation of ecological data for areas where spills are most likely to occur (ports and oil platforms) and for it to be made available in a format useful in emergency environmental planning and responses. The *Rena* incident demonstrated the effectiveness of having such information available and a team of environmental scientists working in conjunction with statutory responders.

Lesson 2. A multidisciplinary team is essential

The scientists investigating the effects of the *Rena* incident were a 'coalition of the willing'. The Te Māori Moana partnership eventually comprised ecologists, chemists, toxicologists, physiologists, ocean modellers, field teams and a range of iwi and stakeholders. Effective engagement between this partnership, the *Rena* Recovery Programme (Ministry for the Environment 2011), MNZ and the 'human resources' of the Bay of Plenty, demonstrated that getting boots on the beach at ground zero was key. In this case, it was fortunate that the oil came ashore on a densely populated stretch of coastline with a ready and able workforce. Had the oil come ashore at a more remote location, the outcome may have been quite different. A critical early component was the refinement of a model of coastal water movement, which allowed an accurate prediction of oil dispersal and where it would land on the coast. These types of models will help immensely if future events occur in remote locations and will assist in mounting defensive and clean-up strategies. The role of local people and the use of marae (meeting grounds and a focal point of Māori communities) in this regard are deemed to be important considerations in future planning for maritime disaster responses in New Zealand.

Lesson 3. The manifest matters

The full cargo manifest of the *Rena* was not available until several months after the ship grounded, which made it difficult to know what contaminants to monitor in the field and to incorporate into subsequent ecotoxicity experimentation. For example, from the manifest, it was not clear what form the copper was in, but from early sampling of reef sediments and biota it was clear that copper from somewhere on the ship was a significant contaminant. Had it been known that the copper was in a finely ground form (clove) it would have been appropriately identified as an ecologically harmful substance and prioritised for recovery before the ship broke up and sank.

Lesson 4. You don't know what will happen next, so plan for surprises

'Back-seat driving' and being wise after an event are a lot easier than dealing with an incident as it unfolds. When a ship grounds, oil is on the water and passions are running high. It requires real expertise, openness and numerous onsite public meetings to keep the public informed and also to let them have their say. As the *Rena* incident unfolded, it was simply not possible to know how much oil would land onshore, if the available responses would be enough to prevent widespread environmental damage, and if the weather would hinder or facilitate clean-up and salvage operations. Furthermore, the full extent of the cargo would not be known for months. The wreck itself, the feasibility of its removal, and the retrieval and containment of debris were always a top priority. The situation was always and will always be complicated by the specifics of location, aspect, swell, position of the ship, extent of the damage, etc. As the head of MNZ said in one public meeting: 'I have grown to realise we are a nation of 4 million salvage experts.' This is the milieu in which responders are operating and planning must be done accordingly. You can take for granted that 'surprises' both fortunate and otherwise are just around the corner. As it ensued, we also did not know for several months just what the largest issues would prove to be. Accordingly, we stress the importance of having onsite environmental scientists from the onset of such potential disasters.

Lesson 5. Environmental resilience helps

The resilience of the Bay of Plenty coastal ecosystem to oil effects, albeit over short periods of time, was significant. This was due in part to the highly exposed nature of most of the coastline and to the rapid removal of oil by hand. In coastal biota, PAH body burdens went up and down quickly (Ross et al. 2016a), the effects of oil were mostly not lethal, and sublethal effects were usually not apparent. Clearly there are thresholds or tipping points for severe ecological effects of ship groundings and oil spills (Jewett et al. 2002). In this case, the volume of oil lost from the *Rena* did not meet this threshold. However, a similar volume of oil in a different setting might result in significant adverse ecological effects. For example, it is likely that the return to a pre-spill environment would be far slower in sheltered estuarine habitats, particularly those with seagrass beds where oil removal would be difficult without destroying the habitat itself. The work reported in this volume adds to our knowledge of ecotoxicity of mixtures of maritime pollutants that are likely to affect a range of New Zealand coastal species. There is a need to expand on this research to understand ecological tipping points and cumulative effects. An important component of this research is the role of microbial communities in the degradation and medication of oils and other contaminants in different habitats (Atlas et al. 2015).

Concluding comments

The role of science in informing and aiding disaster management is not something that has been formalised or necessarily discussed in great detail in New Zealand. In the case of the sinking of the MV *Rena*, science played a significant role in public and stakeholder engagement and possibly even aided in oil spill management in the wider Bay of Plenty. However, at Astrolabe Reef, there appeared to be little scope for science to play an operational role in informing what has turned out to be a complex salvage operation and site remediation. It is uncertain whether different outcomes would have been achieved had there been more opportunities to conduct research at Astrolabe. Regardless, with the hindsight we now have there would certainly be a scientific basis for doing things differently 'next time around'. Without the knowledge and experience gained observing the unfolding of the *Rena* incident, New Zealand's preparedness for future maritime environmental disasters would be less. For example, when oil was spilled during bunkering operations at the Port of Tauranga in April 2015, the oil dispersal model for Tauranga Harbour developed for the *Rena* oil spill (Jones et al. 2016) was able to guide the shoreline assessment and the deployment of clean-up resources. A monitoring programme with comprehensive pre-spill (post-*Rena*) baseline data against which to assess the impacts of the oil spill was also able to be rapidly implemented.

There is little doubt that New Zealand's state of preparedness for maritime disasters is enhanced after the scientific work done in response to the *Rena* event. We know more about the effects of HFO and how it is modified by dispersants and other agents. We know more about how New Zealand fish and invertebrates respond to oil and metal contaminants in both laboratory and field contexts. We know more about the resilience of the marine estate to moderate levels of oil pollution. We have refined oil spill dispersion models. Importantly, we have also experienced the benefit of splicing science with frequent public review and input during a catastrophe. If the adage of 'not letting a disaster go to waste' holds true, one legacy of the *Rena* should be preparedness for future events so that the lessons learned since October 2011 are incorporated into disaster management protocols. The alternative is that this new-found knowledge is either lost or left to gather dust in the (electronic) pages of this special issue, necessitating the same lessons to be relearned at a future date. The insights gained through the studies recorded here increase our capacity to manage the risks associated with ever-increasing shipping, enhanced use of our ports, and the growing oil exploration industry.

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Disclosure statement

Phil Ross is a Research Fellow at the University of Waikato. During the time that this research was conducted, Ross was contracted both by the Bay of Plenty Regional Council and by the owner (Daina Shipping Co.) and insurer (P & I Services) of the MV *Rena* to conduct environmental monitoring and report on monitoring results. Ross was called as an expert witness for the owner and insurer of the MV *Rena* at the Resource Consent hearing in November 2015.

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