PROMOTING EFFECTIVE SPILL RESPONSE

SHIP GROUNDINGS ON CORAL REEFS

TECHNICAL INFORMATION PAPER

18

Introduction

When vessels run aground on coral reefs, the localised physical and ecological effects can be both severe and complex. A vessel's impact on the reef may break and displace coral and other associated marine life. In addition, a grounding will typically result in structural damage to the reef habitat as the coral framework is crushed and flattened by the hull, forming rubble that can smother a wider area. The initial damage can be exacerbated by further movement of the grounded vessel, either due to exposure to strong swells or from re-float attempts. Further impacts can also be caused by jettisoned cargo, towlines, prop wash or anchors. It is beneficial for those involved in the response, and other stakeholders, to be aware of mitigation measures to reduce damage to these sensitive habitats.

Groundings typically require initial damage assessments through underwater surveys, with potential further monitoring over a period of time to track the recovery of the affected site. In some cases, it may also be necessary to implement restoration measures to accelerate the recovery of the habitat.

This paper describes the effects of groundings on coral reefs and provides guidance on response strategies to reduce the severity of damage, survey techniques and restoration measures.

Coral reefs

Shallow water coral reefs are only found in warm waters, occupying less than 0.1% of the world's ocean surface, and yet they account for 25% of all marine species, forming some of the most biodiverse ecosystems on Earth. For this reason, they are often referred to as the "rainforests of the sea". They are ecologically important and provide direct economic services related to tourism, fisheries and shoreline protection, as well as other benefits to society.

Corals consist of colonies of many small individual organisms, known as polyps, which secrete calcium carbonate to form protective exoskeletons around their soft bodies. Along with other organisms that produce a mineral skeleton, such as calcareous algae and molluscs, this forms the underlying foundation of a coral reef (Figure 1).

Coral reefs are complex three-dimensional structures providing a variety of habitats for the multitude of organisms that comprise the coral reef ecosystem.

The overall construction and development of a reef is a very slow process. The growth of individual corals is typically measured in the order of centimetres a year, whereas the overall growth of a coral reef is usually measured in the order of millimetres per year. Some of the more well-established reefs have developed over tens of thousands of years, with individual coral colonies potentially living for hundreds of years.

Reef ecosystems vary globally and regionally in terms of their architecture, biodiversity, complexity, function and health.

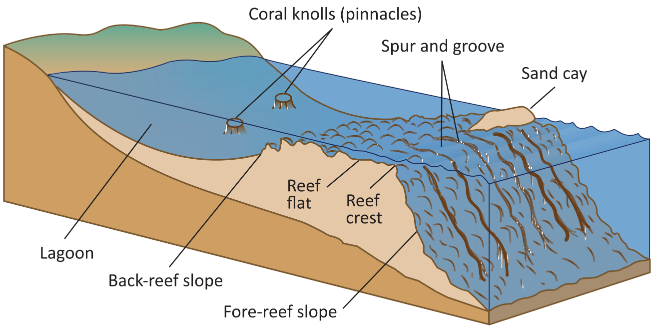


Figure 1: Illustration of a coastal coral reef system

Figure 2: Bulk carrier aground on a coral reef with support vessels in attendance. (Photo by Cocoy Sexcion/Sarangani Information Office)

As with all ecosystems, coral reefs are subject to natural fluctuations in biodiversity and health as a result of variability in physical factors, such as temperature and salinity, and ecological factors, such as predation or competition (e.g. for space) from other biota (such as algae).

In addition, it is widely recognised that coral reefs face a multitude of stresses, both natural and anthropogenic, affecting their health, including: severe weather events; climate change; ocean acidification; overfishing; destructive fishing; coastal development and chronic pollution.

Consequences of groundings

Grounding of vessels on reefs can be a source of significant localised damage. Running aground, and subsequent attempts to free the vessel, may lead to direct physical and biological impact to the reef. Physical damage typically includes the dislodgement of corals, pulverisation of coral skeletons, removal of the reef surface and structural damage to the reef framework, leading to a loss of 3-D complexity (Figure 3). Biological damage can include mortality or displacement of marine organisms. Indirect damage, as a result of the movement of mobile reef boulders, fragments and sediments, can exacerbate these impacts by smothering adjacent areas of the reef, often considerably enlarging the area of impact.

Grounding damage to a reef and its associated flora and fauna can also upset the ecological balance. For instance, once the cohesive reef framework is breached by the hull, propellers, anchors or towlines, unconsolidated material beneath the surface may be exposed. The breached area may expand over time, especially during storms or hurricanes, preventing or delaying the recovery of the reef.

As well as damage caused by the physical impact of a vessel going aground, other impacts may arise from the toxicological effects of any loss of oil or cargo. For further information on the effects of oil on corals please refer to TIP 13 *'Effects of Oil Pollution on the Marine Environment'*.

It is important to recognise that the physical recovery of a reef, especially its architecture, is dependent upon the recovery of reef-building organisms, most notably corals. The loss of coral colonies from an area of reef can lead to two significant consequences. Firstly, the physical structure that creates habitat diversity required to support a variety of marine organisms may be lost and species that are dependent on that habitat will not return. Secondly, a loss of coral creates a risk that the area will undergo a 'coral-algal phase shift', whereby the affected reef is transformed from one dominated by coral colonies to one overgrown with algae, typically resulting in a major decline in habitat complexity and biodiversity. In such a situation, coral assemblages are unlikely to recover and the reef's physical structure may be permanently lost. However, this longer-term process should not be confused with the shorter-term recovery of impacted reefs that re-establish with altered species composition. Variation in an ecosystem's diversity and abundance is commonly observed following large disturbances, either natural or man-made, but they are not necessarily detrimental in the long-term in the same way that a phase-shift might be.

▲ *Figure 3: Physical damage to a reef showing excavation of a section of seabed to the left of the image (Source: Seaground)*

Timelines and patterns of recovery from a vessel going aground vary depending on several factors:

- Vessel size
- Speed at impact
- Time spent aground
- Subsequent movement
- Distribution of rubble

Critically, when considering the potential consequence of a reef grounding, it is also worth noting that the background condition of the habitat will have a significant bearing on its rate of recovery. Well-established, biodiverse reefs tend to be more resilient than those that are already under stress due to the effects of detrimental pressures, such as chronic pollution and/or overfishing. However, even healthy coral reefs are dynamic ecosystems, in a constant state of flux, with both accretive and erosional forces acting continuously upon them and are able to recover over time if the conditions allow.

In addition to the initial grounding, response actions can have a significant bearing on the final magnitude and consequences of the incident. For example, operations may cause collateral impacts such as prop-wash and anchor damage and widen the overall damage footprint.

Initial steps to help minimise damage are shown in Table 1, and key information that is ideally gathered during the initial stages of a grounding for eventual assessment is listed in Table 2.

RECOMMENDED INITIAL ACTIONS TO MINIMISE REEF DAMAGE BY VESSEL GROUNDING

Where possible, and where risk to crew and vessel safety are not further compromised, substrate damage can potentially be mitigated by the following measures:

- Advice should be sought quickly from salvors and other relevant experts to prevent unnecessary damage to the reef;
- Once a decision has been made to refloat the vessel, ideally movement on or over the reef should be minimised, and where possible, the vessel should exit on the same axis by which it entered;
- Ballast or cargo movement should be limited to that necessary for vessel stabilisation;
- Where possible the vessel should be secured with lines or warps in a manner that reduces damage, ideally with floating lines to reduce drag damage;
- The vessel should only be lightered to enable refloating; emergency dumping of cargo should be recorded to include its type, volume and the jettison location.

▲ *Table 1: In the event of a ship grounding, initial steps can be taken to assist salvage works and minimise potential environmental damage caused by the event.*

KEY INFORMATION TO BE GATHERED FOLLOWING A GROUNDING

Maintain a record of all vessel movements prior to, and following, the grounding incident including:

- The vessel's bearing when it first touched and grounded;
- The AIS track of the vessel;
- The GPS position of the vessel's final position fore, aft, and mid-ships both port and starboard;
- Engine or thruster power used when the vessel was aground, or if under tow, the direction and engine power of the towing vessel;
- Details of any manoeuvres or refloat attempts.

The following additional information will also be beneficial:

- Soundings taken around the vessel at regular spacing (~10m) and time of recording;
- Weather conditions during the grounding and at regular intervals whilst aground;
- Local tidal and current conditions.

▲ *Table 2: Key information on vessel movements and local environmental conditions that will be beneficial for eventual assessment of grounding damage.*

Morphology and stages of a grounding

A vessel grounding generally consists of three distinct stages, each of which produces a particular 'damage signature'. These stages are:

Stage 1: Initial grounding

Sometimes referred to as the 'inbound path', this covers the phase from initial contact with reef structures to the final resting position of the vessel (Figure 4).

Stage 2: Time aground

Whilst a vessel remains aground it may continue to damage the reef by:

a) remaining in a fixed position and becoming embedded into the reef framework;

b) moving from its initial resting position to a new position due to environmental forces or salvage operations;

c) or a combination of a and b, whereby the vessel moves several times with distinct resting phases in between, during which the vessel becomes embedded in the reef. This usually occurs when a vessel is aground for an extended period of time.

In addition to the vessel's own movement, salvage operations can generate impacts through loss of cargo, contact by salvage vessels, cables dragging across the reef, anchor points, prop wash or loss of materials.

Stage 3: Vessel removal

Vessel removal can create additional impacts, in particular, if the reef front is 'ripped' away during the operation and large quantities of rubble fall down the reef slope. This can result in smothering of wider areas of benthic habitat.

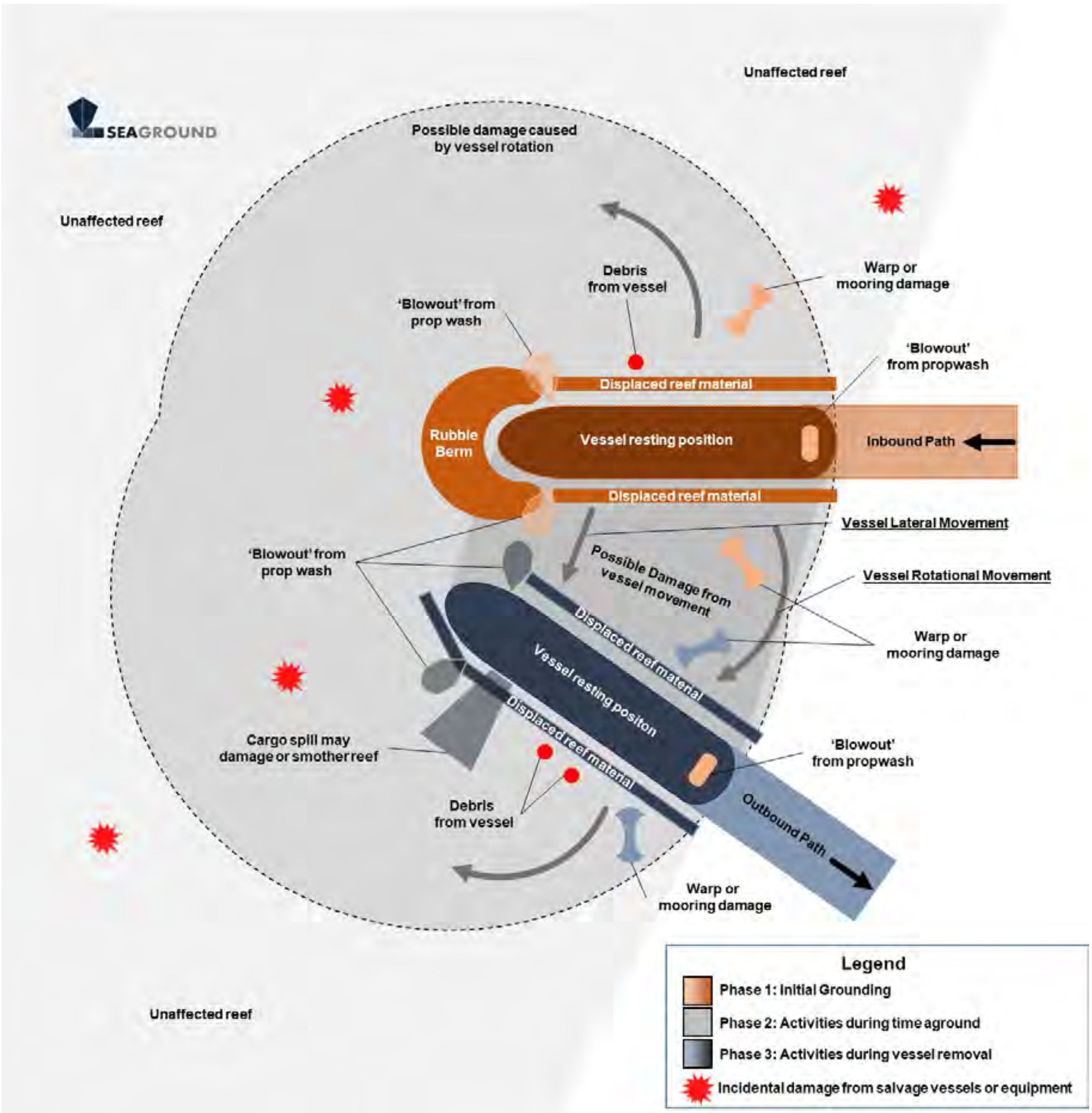


Figure 4: Possible physical damage caused during a vessel's grounding in three distinct phases: the initial grounding, time aground and vessel removal.

Damage assessment

Depending on the scale and nature of a reef grounding incident, local or national agencies may require an assessment of the site to determine the degree of impact and to assess if restoration measures would be appropriate. It is good practice to establish a team of experts representing both government authorities and shipowner interests to perform the evaluation jointly and agree the extent of damage.

Prior to undertaking an assessment, the relevant authorities and vessel interests should engage in dialogue to determine specific aims and the means by which these will best be achieved. A range of survey options exist, requiring a variety of resources to answer different needs of the case. A methodical approach to determine the most suitable options is listed in Table 3 on pages 8-9.

A coral reef grounding survey has the primary purpose of determining the boundaries of the impacted area, whilst also identifying the nature of the damage (e.g. estimating the number, size and species of injured or dislodged organisms), and documenting the potential loss of resource function.

The outcomes of a damage assessment would ideally include a site map, with georeferenced boundaries and the extent of various impacts (e.g. rubble piles, fractured reef framework and transferred antifouling paint). This map should characterise zones that differ in their degree of physical and/or biological loss and characteristics. Where appropriate, details of any dislodged, crushed, overturned or otherwise damaged organisms should be recorded.

To determine the loss of coral reef habitat due to the grounding incident, it is necessary to estimate the likely biological characteristics of the site prior to the grounding. Since it is unlikely that the characteristics of a grounding site would be known in detail before the damage occurs, it is usually necessary to identify a reference site (or sites) for comparison. Once an appropriate reference site (or sites) is selected, it should be agreed upon by all parties and correspond physically and biologically to the affected site. The variation between the affected and reference sites can indicate the loss of reef habitat due to the grounding.

A damage assessment should also identify (quantifiably where appropriate):

a) The occurrence (number and type) of juvenile coral colonies (less than 4 cm diameter) in areas adjacent to the grounding site. This will provide an indication of possible recruitment levels of coral in the site post-grounding as a measure of possible natural recovery (providing suitable substrate is available).

b) Levels of herbivores (fish and urchins) in areas adjacent to the grounding site. This will provide an indication of the degree of potential grazing on algae, ensuring that hard substrate remains available for coral settlement and reducing the risk of a harmful 'phase shift' taking place.

c) Other changes that have taken place as a consequence of the grounding event; these include loss of cargo onto the reef and the presence and position of any anti-fouling paint adhered to reef substrate.

The development of accurate damage assessments as detailed above is imperative to determine the degree of habitat loss and associated ecological impacts.

Following the assessment, results should be discussed between the team of experts to agree upon the level of damage. This information provides understanding of the necessity for any reef rehabilitation work.

Reef rehabilitation

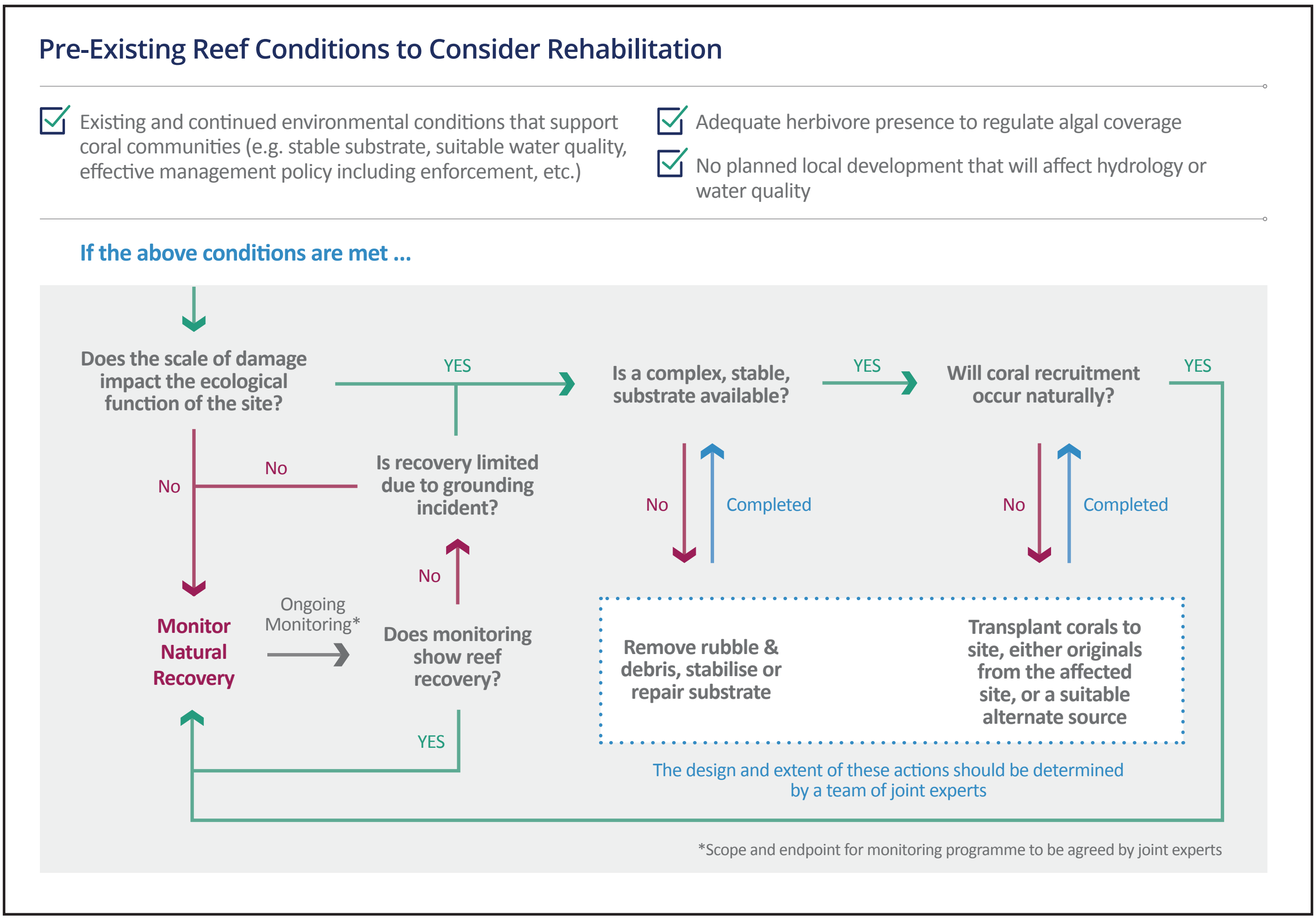
If carried out effectively, a damage assessment can be used to determine the most appropriate course of action to address the impacts at the grounding site. Depending upon the extent and severity of damage, actions can range from monitoring to track natural recovery, to coordinated rehabilitation programmes that mitigate disruption caused by the event.

It is important to consider that response to coral reef grounding damage is not a panacea and the science underpinning reef restoration is developing. Coral reef ecosystems are highly complex and not fully understood to the extent that we can be confident of the outcomes of restoration attempts in every situation. With this in mind, a precautionary, scientific approach is recommended that can be adapted as the project progresses, remembering that the aim of rehabilitation is to assist natural recovery rather than create a new habitat.

Principal factors to determine an appropriate level of intervention include balancing the state of the local environment and the severity of the damage. At one extreme, if local environmental conditions are favourable, the damaged area is relatively small, and there are limited physical impediments to recovery (e.g. loose rubble), the degraded section of reef may conceivably recover naturally within 5-10 years. In such a case, active restoration may have very limited benefits and may even result in further damage through additional disturbance to the habitat. Remediation to remove any antifouling paint or other pollution/materials coupled with simple 'triage' to the site, whereby fractured, dislodged, and overturned coral colonies and other reef organisms are stabilised, may be all that is required to accelerate the recovery period.

Where the severity of damage means a grounding site will not recover through natural processes, then greater intervention to rehabilitate physical and/or biological characteristics of the grounding site may be required.

The degree and nature of reef rehabilitation activities should be based upon scientific evaluation of the site and consensus should be reached between the joint team of experts established prior to the damage assessment. The



▲ *Figure 5: Simplified overview of decisions regarding the necessity and extent of coral rehabilitation work*

decision on the specific actions to be taken is multi-factorial, and ideally driven by: (i) feasibility of the actions; (ii) the extent to which the actions may enhance natural recovery; (iii) the proportionality of the costs. More invasive actions such as the creation of a new habitat are only appropriate when levels of damage mean recovery cannot proceed through natural processes.

Given the physical and biological complexity of a reef system, the criteria for determining aims and objectives of a repair action cannot be based solely on the pre-existing assemblages of coral; structural functions, recruitment, survivorship, and relevant fish and invertebrate populations must also be considered, with due account taken for seasonal variability. Figure 5 provides a simplified decision flowchart to identify the suitability and type of restoration effort required. An overview of some reef rehabilitation options is provided in Table 4.

Further to the ecological factors are socio-economic considerations, wherein interests of affected stakeholder groups should be managed and, where appropriate, their involvement in the rehabilitation process considered.

The degree of impact will typically vary across a grounding site, and therefore rehabilitation actions should be tailored to the pattern of damage and the ecological circumstances (e.g. coral recruitment).

Whether or not active restoration is determined as the best course of action, a monitoring plan will be required to assess the effectiveness of the chosen strategy. As with the initial damage assessment, this plan should include reference sites to better understand the evolution of the grounding site within the context of the overall ecosystem. The monitoring results are used to inform an adaptive reef rehabilitation strategy, allowing enhancement of successful elements, cessation of ineffective measures and inclusion of natural ecosystem flux. As such the identification of requisite parameters is complex, and since resources are limited, a concise plan should be developed and instigated by the joint team of experts.

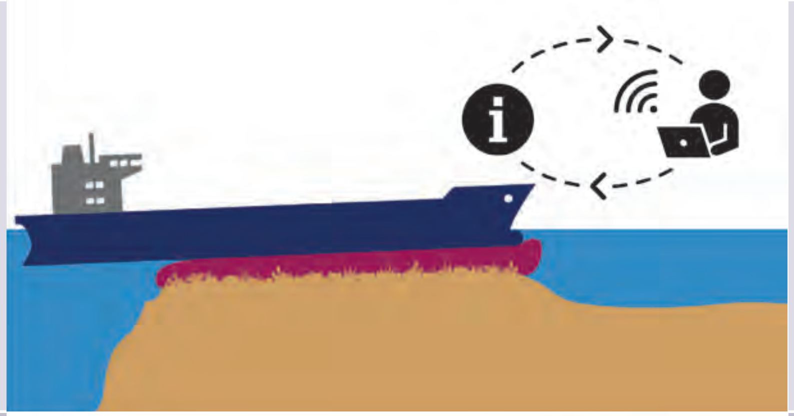
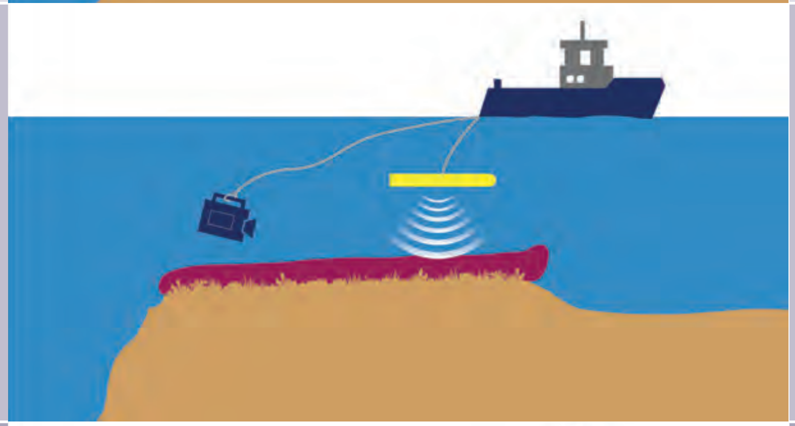
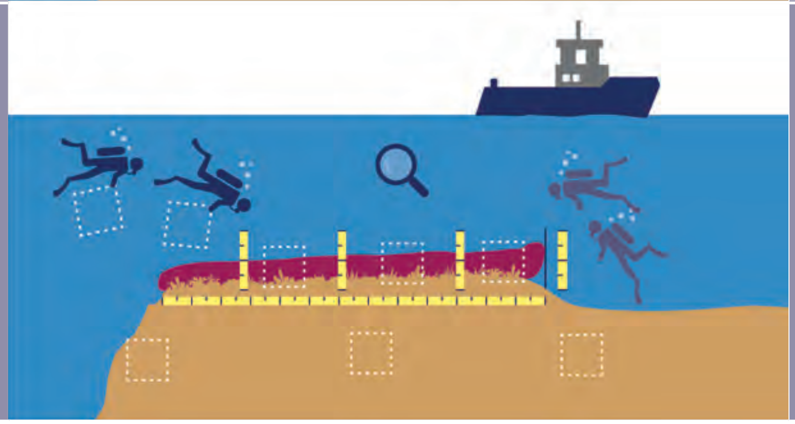
Assessment option	This option should be employed when…	This option answers these questions…	Method
1. Preliminary advice and guidance	• Vessel is aground, about to ground or very recently removed • Details of incident have been obtained • Environmental damage is likely	• Are there ways in which reef damage can be minimised? • What are the expected impacts and damages from this incident in general terms? • Is additional assessment / survey work required? • How can insurers and owners provide services to assist local authorities?	 • Information on the incident is passed to international specialists, who can then assess and advise accordingly • Experts engage and liaise with P&I Club / salvors / local authorities to determine the best course of action • Guidance is passed to relevant parties for their consideration / action
2. Video & sonar survey and assessment	• Vessel is removed • Salvage operations are completed • True spatial extent of damage is unknown • Evidence of the grounding impact is required • Initial reports require confirmation • Logistics of diving or snorkelling surveys may be challenging	• What is the total area of impact? • What area within the total impact site is physically damaged? • What is the degree of physical damage within the site? • How does the impacted site compare to the surrounding area in general? • Is 'biological triage' possible to reduce further damage / impact?	 • Scientific methodology provides supporting evidence of damage • Grounding site is assessed from the water surface • Multiple sensors provide in-depth overview of the physical impacts • Provides rapid information with small team size and reduced logistical requirements compared with dive surveys
3. Diver / snorkel survey: Rapid assessment & recording	• Quality and health of affected area and reference site(s) require clarification • Restoration / remediation is being considered • Initial reports require confirmation	• What is the overall condition and health of the affected area and reference site(s)? • What is the background environmental condition (e.g. indicators of chronic stressors)? • Should restoration / remediation be considered or will natural recovery be sufficient?	 • Divers make a rapid, broad assessment of the affected area • Qualitative information is gathered on the affected area and reference site(s) for comparison, along with other relevant environmental conditions • Logistical requirements may be greater than video & sonar surveys due to increased skilled personnel and support
4. Diver / snorkel survey: Detailed assessment & recording	• Restoration / remediation is likely to be required • Detailed quantitative information on the extent and nature of damage is required	• What are the specific existing conditions of the affected area and reference site(s), including reef profile, species composition and structural complexity? • What is the best course of action with regards to restoration or remediation?	 • Divers closely survey the affected site and reference site(s) • Detailed ecological data is gathered • Logistical requirements are typically greater for this type of operation

Table 3: Potential options for assessing coral reef damage following a grounding. Multiple options may be required for different stages of the case.

		Description	Methods	Conducive circumstances	Additional considerations
INDIRECT	**Proactive management (policy and enforcement)**	• Ensuring adequate protection and management strategies are in place for healthy reef conditions	• Effective fisheries management • Effective water quality management • Stop damaging practices (e.g. via implementing conservation measures)	• Always	• This is required as a component for any successful rehabilitation project
DIRECT	**Biological triage**	• Rapid assessment and mitigation of damage to coral colonies disturbed and displaced by the grounding event	• Re-righting and re-attaching displaced colonies • Moving dislodged corals to temporary protected areas away from potential burial or re-toppling for subsequent re-planting	• During / around initial surveys following grounding incident, if resources allow	• Corals and other organisms repositioned to original orientation • Should be completed quickly after the event in order to improve survivorship of corals that have been displaced but not destroyed (within weeks)
	Debris removal	• Removal of man-made debris stranded on the reef specifically related to either the grounding, or to the removal of the vessel	• Removal of items to less sensitive areas or out of the marine environment	• As a first step of rehabilitation	• Non-toxic / hazardous items may not pose a threat and their removal may be more damaging than leaving in place, especially if they have been colonised by reef organisms • Paint flakes transferred to the reef may contain organotin antifoulants which are toxic and should be disposed of carefully
	Remediating damaged substrate	• Removal or stabilisation of loose substrate impacted by the grounding, which may be unsuitable for coral recolonisation and/or whose mobility could lead to additional damage	• Rubble removal • Substrate consolidation	• When studies demonstrate the condition of remaining corals will be further damaged by movement of loose material and / or the condition of the affected area will not allow successful settlement of new corals, sponges, etc.	• Removal of large volumes may not be necessary if material can be consolidated in situ • Loose rubble that will move around injuring or burying live corals can be removed and placed in less sensitive areas • Utilising rubble generated by the incident to stabilise the reef structure, filling cracks and holes and using cement to consolidate
	Macroalgae removal	• Measures can be taken to remove algae if it has dominated the site due to nutrient loads in the water and / or overfishing of herbivores	• Manual and selective removal as required • Creating habitat to encourage return of grazers to the site	• Once the root cause of algal dominance is remedied by 'indirect' measures, manual removal of algae can potentially speed up recovery	• Immediately following an incident, algae will typically bloom, on healthy reefs, this is only temporary until grazing occurs • The area needs high coral recruitment and adequate grazers for algal removal to be beneficial • This is a labour intensive exercise and should only be a short-term measure • Must be coupled with additional 'indirect' management options such as fisheries management and measures to improve water quality
	Coral predator removal	• Measures can be taken to limit coral predation where overfishing or invasive species have resulted in an abundance of coral predators, inhibiting recruitment	• Manual and selective removal as required	• Once the root cause of coral predator dominance is remedied by 'indirect' measures, selective manual removal of predators can potentially speed up recovery	• Coral predators are a natural feature of healthy reefs, but in some instances they can be over-abundant due to ecological imbalance. An assessment of abundance is required to establish whether there is an imbalance at an impacted site • The area needs high natural coral recruitment for predator removal to be beneficial • This is a labour intensive exercise and should only be a short-term measure • Must be coupled with additional 'indirect' management options such as fisheries management and species management plans
	Coral transplantation	• Corals can be transplanted to the grounding site from nurseries or donor sites, when there is insufficient natural recruitment, and conditions exist for corals to thrive	• Methods can include: (1) Re-attaching corals collected during triage (2) Transplanting corals from donor sites (3) Transplanting corals from a nursery	• When water quality and 'indirect' measures are adequate, and there is a lack of natural recruitment • Suitable donor sites are required for methods involving transplantation from damaged sites	**General considerations** • Prior to any form of coral transplantation, the reef area must be well managed, conditions suitable for coral growth must be demonstrable • Coral transplantation is only used to accelerate natural recovery, not to try and 'recreate' the ecosystem to pre-incident conditions • Coral transplantation is only proven to be an effective rehabilitation strategy at relatively small scales • Organisms should be reattached at similar depths / hydrology and species density and diversity to original or local conditions • Re-attachment can be with cable ties, cement, epoxy **Corals collected during triage** • Broken coral fragments from the grounding site can be raised in another area (nursery) to be reattached later once they have grown stronger and larger **Corals from donor sites** • A suitable donor site is one that has or will suffer damage (e.g. from a storm or coastal development) • Only corals of similar species and growth forms should be introduced • Donor sites should be located in close proximity and be genetically similar **Corals from nurseries** • Sources of donor coral should be from healthy reefs where the volume or species of coral removed will not affect the structure and success of the original site • The distance from the nursery to the site should be short enough to allow corals survival • Nursery conditions should be similar to the site where they will be planted (wave energy, depth etc)
	Replacing damaged substrate	• Where 3D structure and surface complexity is lost to the point where ecosystem function is impaired, artificial substrate can be installed to enable natural recovery	• Methods can include: (1) Consolidating material in-situ (2) Depositing material or structures from other locations	• When water quality and 'indirect' measures are adequate, and there is a lack of suitable substrate for new coral settlement • Evidence of natural recruitment should be present	• New structures must be fixed or heavy enough to be stable during storms • Must be made of long-lasting non-toxic materials • Should exhibit high structural and topographic complexity • Must be placed in an area where reef previously existed and should not exceed the original footprint / volume

Table 4: An overview of some reef rehabilitation options

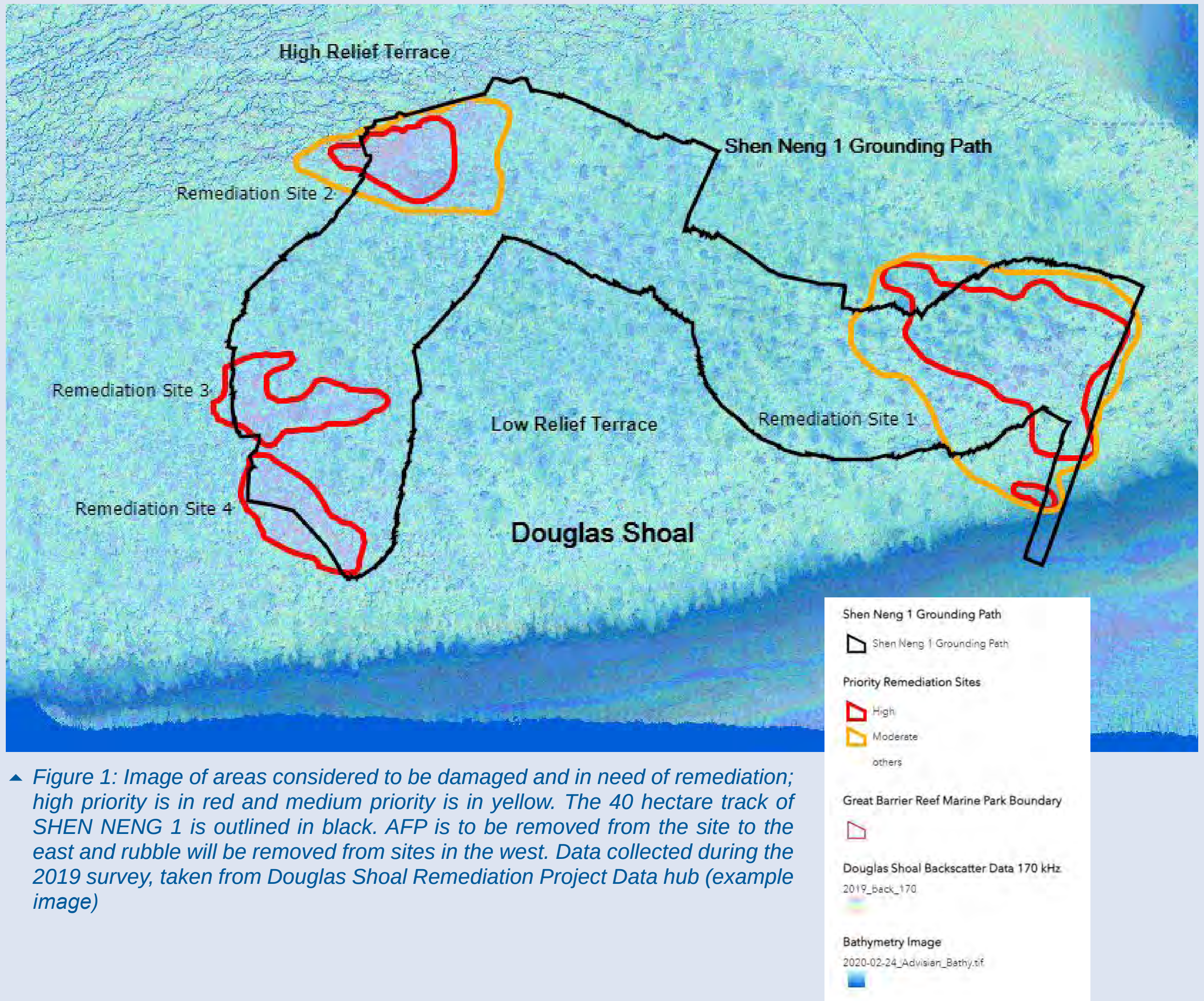
CASE STUDY: SHEN NENG 1

On 3rd April 2010, the Chinese-flagged bulk carrier SHEN NENG 1 (GT 36,575; built 1993) ran aground on Douglas Shoals, approximately 38 NM east of Great Keppel Island, Australia. It was carrying 68,052 MT of coal. The vessel was refloated on 12th April 2010.

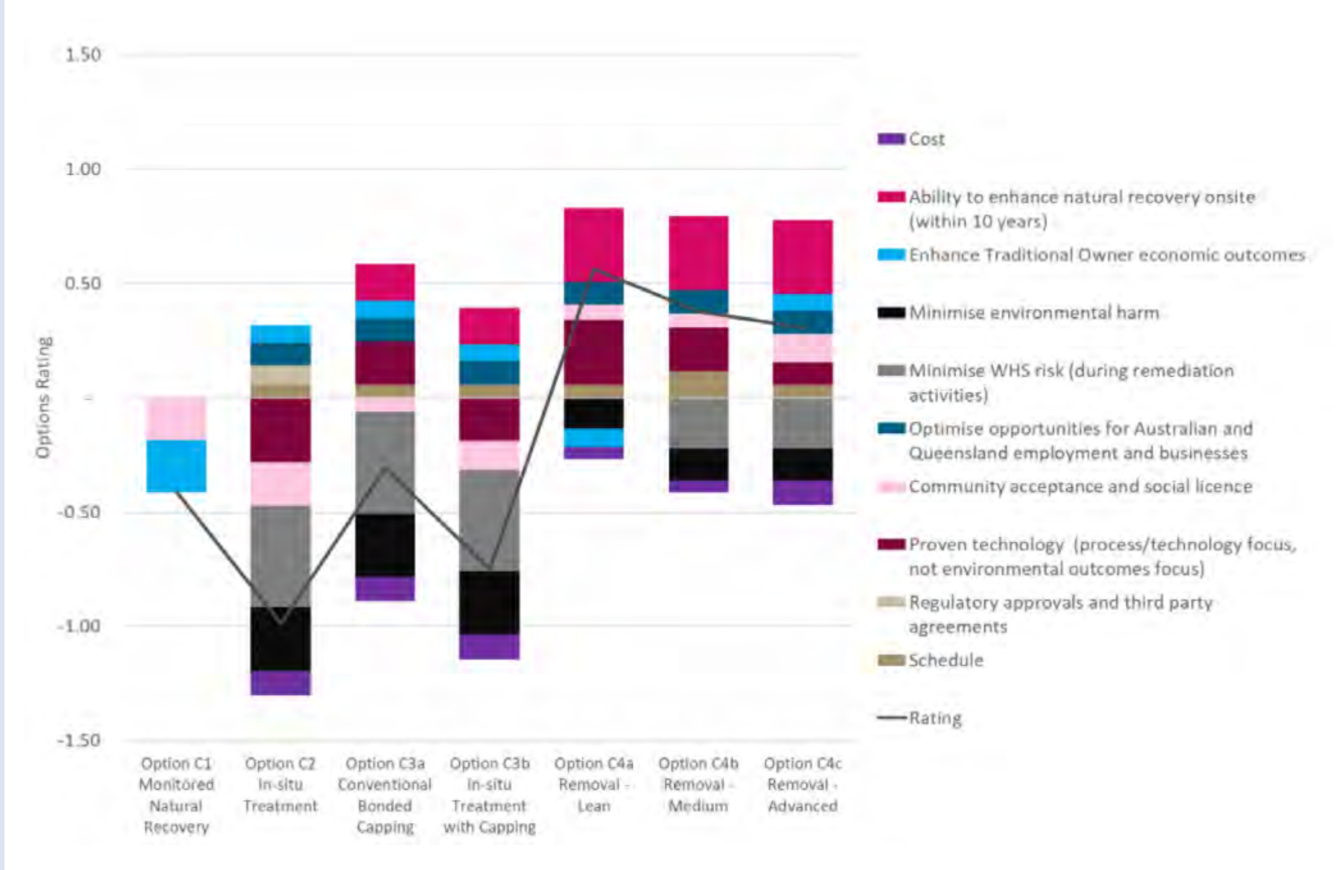
Whilst aground, a small amount of bunker fuel (IFO 180) was lost to the environment and damage was caused by the ship's contact with the reef. Successive high tides raised the vessel allowing westerly winds and currents to move it across 40 hectares (ha) of reef over 10 days. Damage to the environment was not consistent but included both variable levels of physical impacts and the transfer of toxic antifoulant paint (AFP) from the ship's hull to the shoal. Tests highlighted that the ship's historic layers of antifoulant paint contained the highly toxic compound, tributyltin (TBT), banned as an antifoulant since 2008. These chemicals are detrimental to marine life, including corals, and persist in the marine environment, potentially leaching to the environment and bioaccumulating up the food chain.

Damage assessment surveys following the incident were conducted by the Great Barrier Reef Marine Park Authority (GBRMPA), the Queensland Parks and Wildlife Service (QPWS), the Australian Institute of Marine Science (AIMS) and James Cook University (JCU). Using a variety of survey methods, assessments were made to determine the extent of damage, the characteristics of the area prior to the incident and to record AFP present in the sediment. Survey sites were selected within damaged areas and from surrounding unimpacted areas as a comparison.

A joint approach to the damage assessment and development of a rehabilitation programme was not adopted and it took six years for an out-of-court settlement between the owner of SHEN NENG 1 and the Australian government to be reached. The Douglas Shoal Remediation Project was subsequently established as a result.



▲ *Figure 1: Image of areas considered to be damaged and in need of remediation; high priority is in red and medium priority is in yellow. The 40 hectare track of SHEN NENG 1 is outlined in black. AFP is to be removed from the site to the east and rubble will be removed from sites in the west. Data collected during the 2019 survey, taken from Douglas Shoal Remediation Project Data hub (example image)*



▲ *Figure 2: Contamination options analysis using base case, evaluation parameters are shown on the right and potential; solutions along the bottom (taken from Options Analysis Report Executive Summary, Douglas Shoal Remediation Project, GBRMPA)*

The Project's overarching remediation strategy is to support the natural recovery of Douglas Shoal. To guide this, a site assessment was conducted 10 years after the incident (Neale et al, 2019) which indicated AFP contamination and loose rubble were still limiting the natural recovery. Their significance had reduced over time, but measures were still considered necessary to mitigate these two impacts.

To determine the best solution, three potential scenarios were considered for both AFP and rubble removal: no intervention, non-removal and treat in-situ, and removal. Various solutions were presented for the second two options and each was ranked against a number of evaluation parameters (Figure 2) including *inter alia*: cost, ability to enhance natural recovery within 10 years, enhancement of economic outcomes for traditional owners and the wider region, and reduced risk of harm to people and the environment.

The rankings were reviewed and assessed against a variety of weightings to account for cost and preference of the authorities. This ensured a balanced perspective between the various interest groups. An example of the ranked results for AFP removal is shown in Figure 2.

The recommended solution for the area contaminated by AFP was a removal option, the so-called 'lean removal', whereby contaminated material would be removed and treated onshore. The option selected for the rubble also involved stipulated material being removed and treated onshore, thereby creating synergy of resource use.

As of 2021, the project remains ongoing.

https://douglas-shoal-environmental-remediation-project-gbrmpa.hub.arcgis.com/app/a8a7dc45d6ca4094a71fd73d7ef8f89f

Advisian 2020, Douglas Shoal remediation project: options analysis executive summary. Prepared by Advisian Pty Ltd for the Great Barrier Reef Marine Park Authority, Townsville, Australia.

Neale, S.J. and Boylson, B.D. 2019, Douglas Shoal remediation project: Site assessment report. Prepared by Advisian Pty Ltd for the Great Barrier Reef Marine Park Authority, Townsville.

Funding mechanisms for reef assessment & rehabilitation

This document reviews the implications of ship groundings on coral reefs and the direct measures taken to mitigate their effects, commonly referred to as 'Primary Restoration'. Costs will be generated due to these activities, and these claims are typically covered by the shipowner's Protection and Indemnity (P&I) insurer. There is currently no international legal framework that defines admissibility of claims for compensation for environmental damage due specifically to coral reef groundings in the absence of oil pollution or wreck removal. Such incidents are solely governed by national legislation, although in some jurisdictions this may incorporate regulations devised under the International Maritime Organization establishing the amount of compensation available.

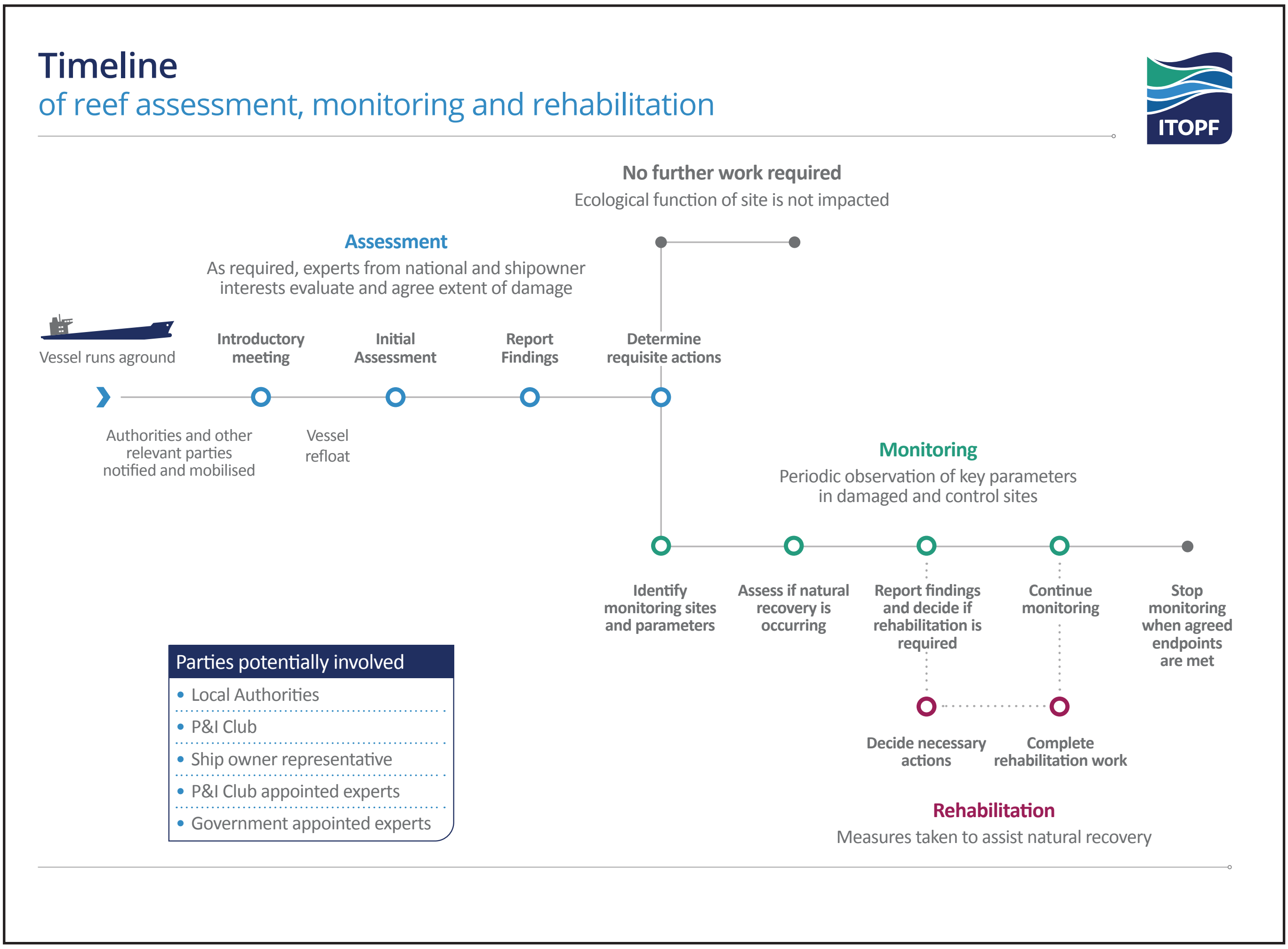
Costs generated by a coral reef grounding incident typically include:

- Assessment of the affected area to establish the extent and nature of damage;
- Longer-term monitoring to track the rate of natural recovery of the site;
- Restoration measures aimed at enhancing the rate of natural recovery of the damaged section of reef.

Economic losses may also occur due to the grounding incident, such as those from local businesses that previously relied on the damaged reef for their income (e.g. SCUBA diving operators).

As discussed throughout this document, close collaboration between local authorities, the shipowner, their P&I insurer, and their respective experts is advisable during the assessment and rehabilitation phases. Early engagement between parties is particularly important in terms of establishing mutually agreed project objectives and a work plan from the outset.

Cooperation is likely to deliver a variety of benefits that enhance the likelihood of common agreement, resulting in an expedited assessment process and the timely provision of funds. In such cases, for example, parties may choose to pool resources (e.g. vessels, surveying equipment, laboratories etc.), eliminating potential logistical bottlenecks. The implementation of a shared data management system, whereby information can be readily accessed by both parties, will generally promote agile decision-making and the ability to regularly communicate a unified plan to a wider spectrum of stakeholders.



Key points

1. Coral reefs are complex ecosystems supporting a range of ecosystem functions; they are susceptible to a wide variety of natural and anthropogenic stressors.
2. Actions taken post-grounding and during salvage operations can have a significant bearing on the final magnitude and consequences of a grounding event.
3. Assessment of coral grounding damage and discussions regarding appropriate actions are most efficiently undertaken using a team of experts that represent both national and shipowner interests.
4. Natural recovery may be adequate, but, if required, there are numerous coral rehabilitation options; however all of them require suitable background environmental and regulatory conditions.
5. Costs related to coral grounding incidents typically include assessment of the affected area, monitoring the rate of natural recovery and, if necessary, rehabilitation methods to aid the speed of natural recovery.

Further reading

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TECHNICAL INFORMATION PAPERS

ITOPF is a not-for-profit organisation established on behalf of the world's shipowners and their insurers to promote effective response to marine spills of oil, chemicals and other hazardous substances. Technical services include emergency response, advice on clean-up techniques, pollution damage assessment, assistance with spill response planning and the provision of training. ITOPF is a source of comprehensive information on marine oil pollution and this paper is one of a series based on the experience of ITOPF's technical staff.

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