Marine Pollution Bulletin 129 (2018) 8–13

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

No evidence of damage to the soft tissue or skeletal integrity of mesophotic corals exposed to a 3D marine seismic survey

Andrew Heyward[a,b,*], Jamie Colquhoun[a,b], Edward Cripps[c], Denise McCorry[d,1], Marcus Stowar[e], Ben Radford[a,b], Karen Miller[a,b], Ian Miller[e], Chris Battershill[e,2]

[a] Australian Institute of Marine Science, M096 UWA, 35 Stirling Highway, Crawley 6009, Australia
[b] Indian Ocean Marine Research Centre, University of Western Australia, WA 6009, Australia
[c] School of Mathematics and Statistics, University of Western Australia, 35 Stirling Highway, Crawley, Western Australia 6009, Australia
[d] Environmental Resources Management, 16/F Berkshire House 25 Westlands Road, Quarry Bay, Hong Kong
[e] Australian Institute of Marine Science, PMB 3, Townsville, Qld 4810, Australia

ARTICLE INFO

Keywords:
Seismic survey
Coral reef
Coral
Damage
Skeleton
Tissue

ABSTRACT

Scleractinian corals, primarily plate corals in families Agaricidae and Acroporidae, were monitored in situ before, during and after a 3D marine seismic survey. An initial four day seismic run, resulting in a maximum 24 h received sound exposure level (SEL_{24}) of 204 dB re 1 μPa^2·s and received 0-to-peak pressure (PK Pressure) of 226 dB re 1 μPa, had no detectable effect on soft tissues or skeletal integrity. Subsequently, a full marine seismic survey (Maxima 3D MSS), proceeded over two months and included seismic acquisition lines at 240 m spacing over the broader reef lagoon (South Scott Reef), generating maximum received SEL_{24} of 197 dB re 1 μPa^2·s and received PK Pressure of 220 dB re 1 μPa at the coral monitoring sites. The analysis detected no effect of seismic activity measured as coral mortality, skeletal damage or visible signs of stress immediately after and up to four months following the 3D marine seismic survey.

1. Introduction

The effects of marine seismic low frequency sound, and indeed anthropogenic noise in general, on marine invertebrates have received minimal attention in the literature (see Carroll et al., 2017; Peng et al., 2015). Responses may include startle reactions, physiological indications of stress, no detectable responses, or observed effects only detected at unrealistically high exposure levels (Carroll et al., 2017). For marine invertebrates generally, seismic acoustic signals have been considered unlikely to result in direct mortality (Department of Fisheries and Oceans Canada, 2004), especially at realistic sound levels, however, more recently a significant impact on plankton has been reported (McCauley et al., 2017). In larger fauna, documented sublethal effects include behavioural changes, reduced growth and declines in reproduction. Findings indicated invertebrates with statocysts, including cephalopods, some crustaceans, echinoderms, bivalves and plankton may be affected by sound in a similar way to fish (Carroll et al., 2017; McCauley et al., 2017). A recent study of lobsters and scallops in Tasmania (Day et al., 2016) found no direct mortality immediately following seismic sound exposure, but indications of stress were observed in both types of organism with an increase in scallop mortality 120 days post-exposure, that correlated positively with the number of acoustic passes (Day et al., 2017). Some of these effects are consistent with damage to the balance organs, but pathways for effects and responses to sound exposure are likely to be complex, varying between species and even between life history stages within a species. Stony corals lack statocyst structures and fluid fills the space between the epithelium and skeleton, reducing their potential to suffer from barotrauma in comparison with species possessing those sensory structures or gas chambers (see Popper et al., 2014). It has been suggested that hydroacoustic force could potentially cause skeletal and tissue damage in corals, although at unrealistically high levels ~260 dB re 1 μPa (Hastings, 2008). Consequently, although noise exposure could have an effect on spawning, developing embryos, larvae or settling recruits, adult corals may demonstrate a response via the physical force of sound pressure levels directly affect the soft tissues and stony skeleton. While direct mortality of invertebrates from hydro acoustic force has been considered unlikely (Department of Fisheries and Oceans Canada, 2004), there have been no field studies assessing skeletal or tissue integrity in reef building corals exposed to real world levels of

* Corresponding author at: Australian Institute of Marine Science, M096 UWA, 35 Stirling Highway, Crawley 6009, Australia.
E-mail address: a.heyward@aims.gov.au (A. Heyward).
[1] Current address: Woodside Energy Ltd., 240 St Georges Terrace, Perth, Australia.
[2] Current address: School of Science, University of Waikato, Tauranga 3110, New Zealand.

https://doi.org/10.1016/j.marpolbul.2018.01.057
Received 31 August 2017; Received in revised form 5 January 2018; Accepted 26 January 2018

seismic acoustic signals from commercial air gun arrays.

Commercial air gun arrays used in seismic surveys associated with oil and gas exploration produce high energy, intense and primarily low frequency acoustic signals. The planned footprint of a northwest Australian seismic survey at Scott Reef, named the Maxima 3D Marine Seismic Survey (MSS), overlapped with a mesophotic, coral dominated habitat in the reef lagoon. The sheltered lagoon at South Scott Reef is 30–70 m deep and covers approximately 300 km^2. Despite being a low light environment it is a rich benthic primary producer ecosystem, with numerous algae and in places, abundant Scleractinian coral (e.g. Cooper et al., 2010).

Here we present results from the first in situ experiment of its type, focusing on the effects of a seismic survey over a coral reef. The study monitored the immediate before and after effects on mesophotic corals of exposure to airgun acoustic signals within the south Scott Reef lagoon, with a series of repeat surveys spanning four months, just prior to, during and following the period of acoustic exposure, to assess responses of the dominant coral group.

2. Methods and equipment

2.1. Coral habitat survey

Previous surveys throughout the Scott Reef lagoon with ROV (Heyward et al., 2000) and towed video (Smith et al., 2006) mapped the distribution of major habitats. The lagoon basin covers approximately 300 km^2, from the base of the back reef slope at around 30 m depth, into a central basin 40–50 m deep, extending and shallowing slightly to 35–40 m toward the northern perimeter of the reef lagoon platform before it deepens sharply beyond 70 m, into a deep channel > 400 m. The central lagoon basin, representing 42% of the lagoon area, supports extensive coral-dominated habitat with high to very high cover (30–90%) of Scleractinian corals, but also areas where corals alternate with sand, rubble and algae (Fig. 1).

Standard AIMS towed video techniques (Heyward et al., 2012) were used across the lagoon to delineate areas of comparable mesophotic coral habitat. Plating/foliaceous coral species (*Montipora* spp., *Pachyseris* spp., *Leptoseris* spp., various Pectinidae and others; see Fig. 2), formed dense coral communities in places, including extensive monospecific patches. Branching coral species (*Acropora* spp., *Leptoseris* spp., *Seriatopora* spp.) were less abundant, but contributed high cover in mixed habitats where calcareous algae such as green branching *Halimeda* spp., fleshy and encrusting red algae and zooxanthellate octocorals including *Sarcophyton* spp., *Lobophytum* spp. and *Sinularia* spp. were recorded.

Eight comparable assessment sites, each of sufficient spatial extent to accommodate three drop camera photo transects separated by at least 100 m, were identified. Along each transect a minimum of 30 photo quadrats, at an average spacing of 6 m, were taken by a continuously strobing camera held at a consistent distance off the bottom to achieve a 1 m^2 photographic area of seafloor, and 15 photo quadrats per transect were selected for subsequent quantitative analysis. Images were examined using an acetate squared grid (750 squares) overlay, counting the number of grid intersects to quantify live coral cover, dead coral, encrusting red algae and soft coral. Soft corals (*Sarcophyton* spp.) were also examined to note the extent that polyps where extended, with particular notice taken of soft coral morphology immediately after Seismic passes.

Assessment of hard coral skeletal and soft tissue damage, focussed on the dominant plate forming species, in the families Agariciidae and Acroporidae including *Pachyseris speciosa*, *Leptoseris foliosa* and *Montipora aequituberculata*. Damage to corals was assessed as recent breakage where bright white cracks were visible or tissue lesions exposed subsurface coral matrix. There was evidence of natural damage and old breaks, also bites and disease, and these were classified accordingly. Older scars/breaks could usually be identified as they were in the process of healing, with evidence of fresh surface tissue/colour or rounded edges (or they had visible signs of infection, which was considered not possible for fresh one day old breaks). Breakage associated with predation, such as feeding scars, was usually evidenced by circular patterned breaks and scrapes over the surface of the corals.

Monitoring sites were surveyed three times; before any seismic activity, immediately following the initial 4 day trial in the central lagoon, then two months after the completion of the full 3D marine seismic program survey over the entire lagoon (see Fig. 1 & Table 1). Each coral assessment surveyed the 8 sites, each with 3 transects. The resulting data set generated 1080 photo observations (3 surveys by 8 sites by 3 transects by 15 photo quadrants). The sites and transects locations were located by GPS, to enable them to be revisited for each survey. However a small degree of spatial imprecision was associated with the repeated transects, due to differing current and wind conditions slightly altering the path of the survey ship or towed camera platform, in turn altering the seafloor areas actually photographed during each towed transect. This was a desirable effect as the design proposed that sites and transects be randomly selected, but within comparable benthic habitat type (hence the approximate relocation to general site coordinates identified from the preliminary towed video habitat surveys).

2.2. Seismic survey

A 3D marine seismic survey was conducted between September and December 2007 over an area of approximately 362 km^2, including North and South Scott Reef (collectively known as Scott Reef), situated approximately 430 km north of Broome in Western Australia (Fig. 1). The technical details of the 3D marine seismic survey are as described in Miller and Cripps (2013). A 2055 cubic inch (total volume) short pulse (< 200 ms), low frequency (< 500 Hz), acoustic emission dual source array was towed behind a slow moving (≈4.5 kn) dedicated survey vessel (MV Veritas Voyager) with a shot point interval of 18.75 m. A minimum interval of 6 h elapsed between seismic discharges on adjacent sail lines (passes) that were 240 m apart. Sound Exposure Levels (SELs) were mapped and measured before the completion of the full 3D marine seismic survey using sea noise loggers set in various places within the lagoon (McCauley, 2014). Much of the survey over the lagoon habitats was in waters 40–60 m deep, with the entire survey also including areas beyond the reef extending to depths of approximately 500 m (see Miller and Cripps, 2013). An initial seismic run was conducted along the seismic line indicated in Fig. 1 (blue line over sites 1–4) between the 13th and 18th of September. The initial four day trial recorded a maximum 24 h received sound exposure level (SEL_{24}) of 204 dB re 1 $\mu Pa^2 \cdot s$ and received 0-to-peak pressure (PK Pressure) of 226 dB re 1 μPa at the coral monitoring sites and maximum received SEL_{24} of 144 dB re 1 $\mu Pa^2 \cdot s$ and received PK Pressure of 163 dB re 1 μPa at reference sites > 3 km away. Subsequently the full Maxima 3D MSS was conducted between 19th September and 17th November 2007 throughout the Reef (Fig. 1). Maximum received SEL_{24} of 197 dB re 1 $\mu Pa^2 \cdot s$ and received PK Pressure of 220 dB re 1 μPa were estimated at the coral monitoring sites during the subsequent 59 day seismic survey (McCauley, 2014), which covered the majority of the lagoon (see Fig. 1). Further assessment of the coral monitoring sites at the conclusion of the seismic survey, together with the initial measurements, were used for an analysis of the cumulative effects of seismic surveys on the dominant plate type corals.

2.3. Statistical analysis

Plate and foliose type corals (see Fig. 2) which together comprise approximately three quarters of the hard coral cover in the deeper central lagoon at Scott Reef, covered by the seismic survey lines (see Fig. 1), were the focus of the analyses reported here. It was hypothesized that longer term effects, including sub lethal effects, may present as an increased proportion of diseased colonies, overgrowth by