Seismic Surveys Have Little Impact on Demersal Fishes

A large-scale three-year experiment recently quantified the impacts of exposure to a commercial seismic source on an assemblage of tropical demersal fishes targeted by commercial fisheries on the North West Shelf of Western Australia. Monitoring of the composition, abundance, behavior, and movement of the fishes was pursued in multiple before-after-control-impact and dose–response experimental frameworks using acoustic telemetry and underwater video. The multidisciplinary team of scientists, technical staff and industry experts found there were no short-term (days) or long-term (months) effects of exposure on the composition, abundance, size structure, behavior, or movement of this fauna. These multiple lines of evidence suggest that seismic surveys have little impact on demersal fishes in this environment.

Elements of results from the published study are summarized and highlighted.

The NWSSRP Study and the Marine Seismic Noise Measurement and Impact Theme

In 2017, the Australian Institute of Marine Science (AIMS) and its partners commenced the North West Shoals to Shore Research Program (NWSSRP), a three year, A$20 million study of the North West Shelf of Australia (refer to Figure 1). The program of 11 separate studies within four main themes has been conducted by a multidisciplinary team of scientists, technical staff and industry experts. Each of the four themes addressed gaps in scientific knowledge relevant to the environmental management of the offshore petroleum industry in north-western Australia, and are as follows:

- **Theme 1: Marine seismic noise measurement and impact** (considered in this article):

  Describe the acute and chronic effects of seismic and vessel operations under real-world conditions.

- Theme 2: Seabed habitats and biodiversity:

  Examine the ecological processes that maintain benthic communities on both ancient and contemporary coastlines.

- Theme 3: Protected and iconic species movements and threats:

  Assist the quantification and mitigation of the risks vessel movements, industrial infrastructure and activities pose to marine megafauna on the North West Shelf.

- Theme 4: Understanding the isolated coral atolls of the North West Shelf: The past, present and future of Rowley Shoals:

  Develop a habitat model and adaptive monitoring program that informs the future condition of these remote coral reef atolls.

The NWSSRP Symposium was held on September 23 and 24, 2020 and marked the completion of the Program.

Theme 1 (Marine seismic noise measurement and impact) comprised two large and significant experiments that investigated the effect of marine seismic surveys on both fish and peal oysters, respectively. The paper titled '**A large-scale experiment finds no evidence that a seismic survey impacts a demersal fish fauna**' by Meekan et al. (2021) was published in the Proceedings of the National Academy of Sciences of the United States of America (PNAS), and addressed the first experiment results. Content herein is drawn heavily from that paper. A second experiment was also pursued to determine what is the nature and extent, if any, of the impact of seismic surveys on mortality, physiology, growth and production of market quality pearls by pearl oysters. As the roughly 7 000 oysters seeded with peals are still in the process of being grown out for two years to maturity, that study has not yet concluded; however, results are expected in late-2021.

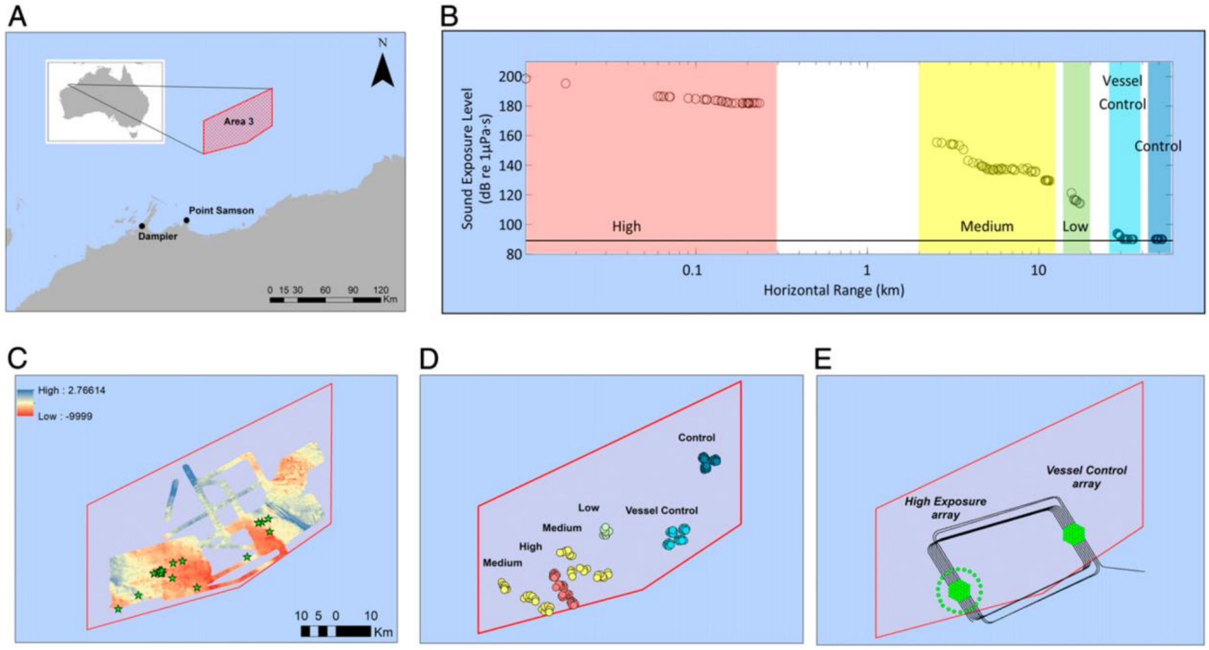
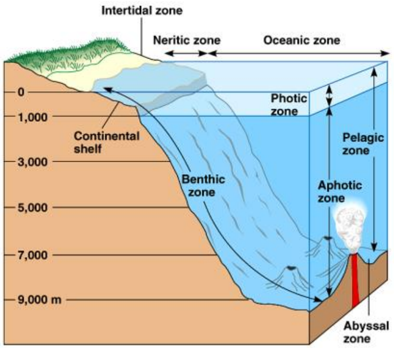


Figure 1. Setting and layout of a large-scale experiment to examine the effects of seismic exposure on demersal fish assemblages. (A) Map of study area within the fishery management location Area 3, where all fishing is prohibited. (B) Modeled maximum SELs at sampling sites in the high-exposure (red), medium-exposure (yellow), low-exposure (green), vessel control (light blue), and control zones (dark blue). The black horizontal line shows ambient sound pressure levels. (C) Locations of sensors for passive acoustic monitoring (green stars) deployed at and near the high-exposure and vessel control zones during the period of seismic exposure, overlaid on a map of backscatter from a multibeam survey of the seafloor (backscatter levels in decibels shown by color bar; SI. (D) Locations of BRUVS sample sites in exposure zones (high—red, medium—yellow, low—green, vessel control—light blue, and control—dark blue). (E) Locations of acoustic receiver arrays (green points) and seismic vessel sail lines (black lines) in Area 3. From [Meekan et al. (2019)](), Figure 1.



The cartoon on the left shows the marine features common to a continental shelf, including the pelagic and benthic zones. The benthic zone is the ecological region at the lowest level of an ocean, including the sediment surface and some sub-surface layers. Pelagic fish live in the pelagic zone – being neither close to the bottom nor near the shore – in contrast with demersal fish that do live on or near the bottom (the demersal zone).

The NWSSRP study area had gently-sloping seabed depths between 50 m and 80 m, and is of similar environment (depth, habitat and biogeography) to nearby fishery zones.

Terminology Used in the Study Results

- Air-Gun: Originally called ‘Pneumatic Acoustic Repeater’ when first developed in the 1960s, an air-gun is typically a metal cylinder containing two internal chambers separated by a moving shuttle. When the air pressure in one chamber reaches 2000 psi, the shuttle opens and air is released through ports in the wall of the second (‘firing’) chamber into the surrounding water. The underwater photo on the left shows an array of air-guns moments after every air-gun was ‘fired’. Compressed air quickly disappates. The rate of sound decay follows geometric laws according to distance, the water depth, and the physical properties of the seafloor geology and underlying sediments.

- The goal of 'Dose-Response Assessment' is to quantitatively describe the relationship between the extent of exposure (the dose) and the likelihood of adverse effects (responses). In practice for a marine sound exposure study, fish samples experience a range of Sound Exposure Levels (SELs) corresponding to a range of distances and azimuths from active seismic events.
- MBACI: Multiple Before-After Control-Impact: The sampling design of the experiment provided a binary comparison between exposed and control zones. The potential impact of response was measured as the difference in the response variable (e.g. abundance) before and after exposure at the control zones.
- Sound Level: For underwater acoustics the description of pressure is usually defined according to a reference pressure (p_0) of 1 μPa at a distance of 1 m, and correspondingly, the level of a sound metric is defined as the logarithm of the ratio of the quantity being considered to its reference value.
- SEL: Sound Exposure Level, the level quantity most often used for auditory damage risk criteria, especially for marine mammals. One of the potential consequences of sound exposure to marine animals is noise induced hearing loss (NIHL), of which there are two types: those caused by acoustic trauma from a very high-level of sound (typically) short duration, and those that occur from exposure to lower level sounds that are presented over substantially longer time periods. SEL is integrated (or summed) over a *time interval*, and continues to increase with time when non-zero pressure signals are present. It therefore can be construed as a dose-type measurement, so the integration time used must be carefully considered in terms of relevance for impact to the exposed recipients.
- SPL: Sound Pressure Level, based upon the greatest absolute value of the sound pressure during a specified time interval and for a specified frequency range.

Summary of Theme 1: Marine Seismic Noise Measurement and Impact

Theme 1 was an A$6m project that ran from May 2017 to June 2020, and was funded by the Good Standing Agreement (GSA) associated with Santos Ltd. The nature of this source of funding is that if a titleholder of offshore Australian petroleum acreage defaults on a guaranteed work program commitment, a GSA is a policy mechanism available for the titleholder and their directors to maintain 'good standing' with the Joint Authority that administers offshore petroleum exploration programs. The Joint Authority may consider on a case-by-case base to make available regional studies as a mechanism to discharge the GSA amount:

- Data generated from a regional study will become 'open file' in an agreed timeframe with the Joint Authority and is to be of interest to the broader petroleum industry, and
- Studies must be completed within three-years from the date of the GSA.

These GSA funds available from Santos enabled a substantial scope to the three-year NWSSRP study, and the experiment was the first of its kind to use used dedicated seismic vessels. For further GSA information, refer to 'Good Standing Agreement: Regional Studies' and 'Offshore Petroleum Exploration Guideline: Work-bid'.

Experiment Design

The fish experiment was conducted within the 2 500 square kilometer fishery management zone of the Pilbara Fish Trawl Fishery ('Area 3') closed to commercial fishing. Locations within this area with suitable and similar fish habitat sites were selected to provide differing levels of exposure (including control sites) for monitoring fish abundance and behaviour. 387 red emperor (Lutjanus sebae—the focal species) were captured and tagged with assistance of local commercial fishers and the Department of Primary Industries and Regional Development to measure movements in response to the seismic survey. The pearl oyster experiment involved the collection, deployment, retrieval and assessment (using scientific and commercial measures) and deployment of more than 10 000 oysters at various distances and therefore exposure levels from the seismic sail lines.

Figure 2 shows the 16 racetrack seismic vessel 'sail lines' and the proximity of various BRUVS (Baited Remote Underwater Video Systems) and acoustic telemetry sampling sites in Area 3. There has been little historical seismic activity in the past decade, however, two shipping lanes do affect the study area: one running N-S about 10 km along the western margin of Area 3, and one running SW-NE through the center of the study area. Active seismic operations with all air-guns operating normally were used for the 8 western sail lines in Figure 2 (and 'High Exposure array' in Figure 1E), and the 8 eastern sail lines (and 'Vessel Control array' in Figure 1E) were recorded without air-gun operations (only vessel noise being recorded).

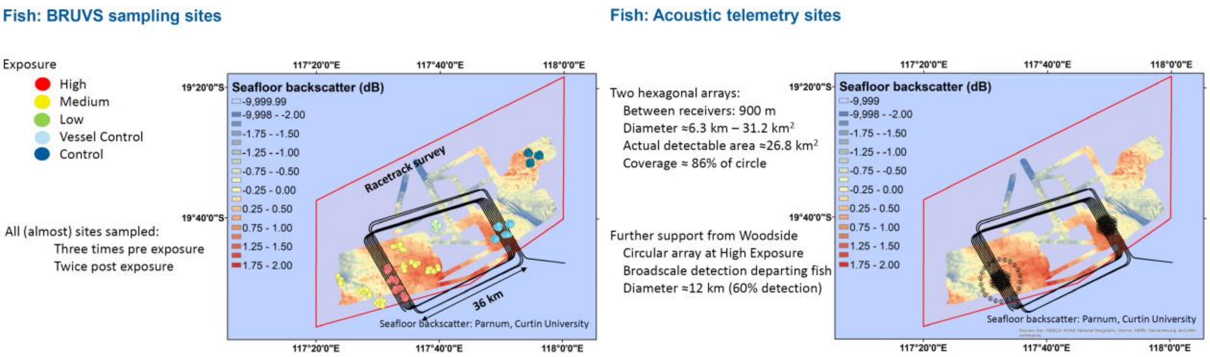


Figure 2. (left) BRUVS sampling sites in Area 3 (refer to Figure 1A); and (right) Acoustic telemetry sites. From '[Design and implementation of a realworld experiment to investigate the effect of marine seismic survey on fish and pearl oysters](#)', slides 16 and 17.

To assess the acoustic exposure levels experienced by demersal fishes and pearl oysters from air-gun array 'shots' fired during the seismic sail lines operated during the two experiments, more than 50 deployments of pressure, particle velocity and ground motion sensors were deployed over the eight-month study. This produced more than 100 datasets, including long-term observations of the soundscapes and biological sounds (refer also to Table 1). Note that a variety of different acoustic metrics were used because different fauna are receptive to different components of seismic signals: Mammals are more receptive to variations in pressure, fish are more receptive to variations in particle motion, and invertebrates connected to the seafloor are more receptive to variations in ground motion.

Sensors deployed during the exposure period collected ≈70,000 recordings of individual seismic shots at various ranges and azimuths from the air-gun array, across the two experimental sites. These measures were used to validate previous Curtin University models of propagation losses at each experimental area. Interpolating across range and azimuth provided an estimate of individual shots (totalling >1,000,000 estimates for each of ten acoustic metrics) and cumulative exposure levels at each of 179 (144 fish and 35 pearl oyster) biological sampling sites.

A key relevant question for commercial fishing operations is "Do the fish move away in the area of a seismic survey?". More specifically, for a tropical fish assemblage, is there an impact of seismic survey activity on the abundance, distribution and community structure of fish; including behaviour or movement. Rather than focus on a single species of fish, the NWSSRP study chose to focus on an *assemblage* of demersal species (refer to Figure 3) as fisheries in Northwest Australia predominantly trawl and trap demersal fish. Red emperor were chosen as the focal species because they are commercially and recreationally important across tropical Australia, abundant, resilient to capture from depth and tagging, and site-attached with a limited home range.

Method	**Information Gathered**
Seismic	Ten days of operation completed on time, including 14 active lines across two sites (8 at the fish study site, and 6 at the pearl oyster site).
Passive acoustic sensing	>130 datasets of passes from the seismic vessel (including active and inactive air-gun operations) across the two sites > 100,000 air-gun shot recordings at discernible signal-to-noise level
Acoustic tagging	387 fish tagged and tracking data recovered for ≈6 months from 98 acoustic receivers
BRUVS	584 deployed
Echosounder (fish)	Transects conducted at High Exposure and Vessel Control sites before and after exposure
Oysters	10,880 oysters either exposed (seismic and/or vessel only) or at a control site

Table 1. Data summary: Fish and oyster sampling.

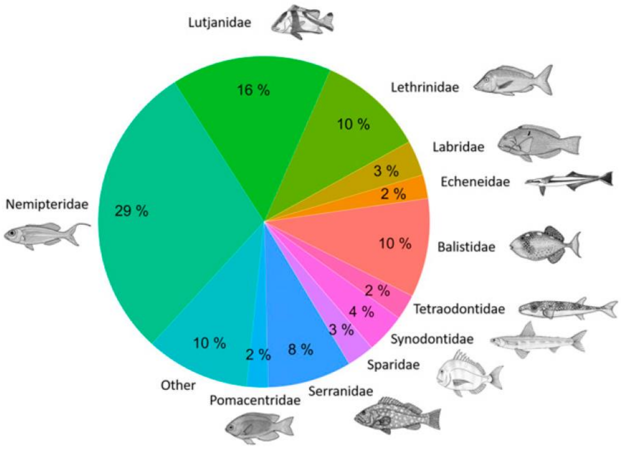


Figure 3. Proportional abundance of demersal fish families observed on all BRUVS surveys. The top 10 contributing species are shown, including the following: Su = Saurida undosquamis, Sf = Sufflamen fraenatum, Sm= Scolopsis monogramma, Pm= P. maculatus, Ss = Scarus sp3 (yet to be formally named Scarus hutchinsi), Pi = Parupeneus indicus, Cc = Choerodon cauteroma, Lp = L. punctulatus, Em = E. multinotatus, and Ls = L. sebae. Initials of commercially important species are in gray font. From [Meekin et al. (2021)](), Figure 2.

During the fish seismic exposure experiment, demersal fishes were observed in five sampling surveys over a six-month period (three before and two after exposure), using BRUVS. In addition, two acoustic telemetry arrays (one each in the high exposure and vessel control zones), tracked the movements of acoustically tagged red emperor, to observe any displacement of the fish, as a result of the seismic survey. During each sampling survey, BRUVS were deployed at 144 locations (629 deployments in total) at various distances from the seismic sail lines. Relative abundance, fish length and behavioural measures were recorded for each species. This provided quantitative data on abundance, community structure and behaviour of the demersal fish assemblage in the area before and after the seismic survey with a focus on six commercially important species, including red emperor.

Exposure Levels

The BGP Explorer towing two full-size (2600 cubic inch) air-gun arrays fired at 2000 psi conducted active and control (guns inactive) sail lines at both the fish and pearl oyster sites. Source modeling predicted an effective source level directly below the array of:

- 228 dB relative to (re) 1 μPa^2.s SEL.
- 247 dB re 1 μPa peak-peak pressure (SPL), and at 15° below the horizontal (strongest direction of emission).

Most of the acoustic energy occurred below 100 Hz, and almost all of it below 1 000 Hz, with peaks at 0 and 50 Hz above an average ambient mean square pressure of 84 dB re 1 μPa.

Pressure, particle velocity and ground motion were observed to be highly correlated (linear relationship) in the 'far-field', where the emitted sound from all air-guns is propagating in phase. Pressure and ground motion were also observed to be highly correlated (linear relationship) at close ranges (down to ~50 m range). Overall, the detailed analysis of the various soundmeasurements concluded that SEL is a good proxy for all tested exposure metrics in the far-field, but requires further data to confirm its ability to predict particle motion in the near-field and transition zone between near- and far-fields. Note that these observations relate to the physics of sound propagation at the test sitrs, and are primarily relevant to any future studies that seek to predict one type of measurement (e.g. pressure) based upon another type of measurement (e.g. particle motion).

Experiment Validity

With regards to the choice of demersal fish considered, the NWSSRP study focused on a tropical shelf environment within a depth range of 50 to 70 m, where habitats are patchy at multiple spatial scales. In this system, the fishery targets a very diverse range of species; none of which exclusively dominates catches. Because of the multispecies nature of the fish catch and the sparse distribution of habitat, the principal aim in this study was to examine evidence for impacts of seismic surveys in the assemblage rather than the responses of a few abundant species.

With regards to the choice of study location, it is unlikely that other, earlier seismic surveys in the general region of the study area may have influenced results. With the exception of one survey that occurred 6 years before the experiment, all activity took place more than 10 years prior to the study.

Acoustic data, abundance and length data and acoustic tracking data for fish is publicly available from AIMS; see https://apps.aims.gov.au/metadata/view/12f7edac-050f-42b9-9d6b-8eac55d102a1

Study Observations

According to Meekan et al. (2019), analysis of the videos provided by the BRUVS in the MBACI experimental design found no evidence for major changes in the assemblage structure or species richness of fishes that could be attributed to seismic source exposure:

- The relative abundances of all demersal species and all target species remained consistent across sampling surveys at an overall mean of 31.61 per hour and 19.66 per hour, respectively.
- There was no evidence for a significant decline in the relative abundance of any species or group of fishes in the high-exposure zone re control zones following exposure to the seismic source.
- There were no changes in the abundance of the entire assemblage, in combined species targeted by commercial fisheries or key families of commercial importance, after exposure to the seismic source. Analysis of individual species that were abundant and/or targets of commercial fishing also showed no significant declines in abundance (refer to Figure 4).
- There was a trend of a slight increase in abundance of all species combined and all target species in the high-exposure zone following exposure to the seismic source.
- There was either no change in abundance at the level of families or species or small, non-significant trends indicating either increases or declines following exposure.
- The dose-dependent analysis also found no significant trend in the abundance of fishes with increasing distance from the seismic source.
- There was no consistent change in the mean sizes of species that were abundant and valuable targets of the commercial fishery following exposure to the seismic source. The sizes of two species were nearly identical before and after exposure, whereas three showed a small trend to larger size (<2 cm on average).
- There was also no change in time to first feeding on BRUVS baits by the commercially important and/or abundant species or any change in the distance that fish were likely to approach the BRUVS following exposure to the seismic source.
- Fishes can show immediate behavioral reactions (startle reflex, schooling, flight, etc.) to seismic surveys or air-guns, although these responses can be inconsistent, and some species appear to adapt rapidly. If these behaviors did take place in the study, they had no measurable short- (days to weeks) to long-term (months) impacts on abundance or the behavior of demersal fishes in the experimental area.
- Consistent with results from the BRUVS surveys, acoustic telemetry found little evidence that red emperor fish was displaced by the exposure to the seismic source.

Summary Comments

The results in Meeken et al. (2021) address the concerns frequently voiced by commercial fishing stakeholders over the negative impacts of seismic surveys on catches of demersal fishes in this environment, at least for the suite of site-attached species that were the subject of their study. The results of the associated pearl oyster study are expected in late-2021.

Acknowledgments

This summary and the content herein was written independently and without contributions from the NWSSWR participants. Refer to Meekin et al. (2021) for the full suite of conclusions.

Further Reading Material

- Measurements of Acoustic Pressure, Particle Motion and Ground Motion. NWSSRP symposium presentation (2020).
- Design and Implementation of a Real-World Experiment to Investigate the Effect of Marine Seismic Survey on Fish and Pearl Oysters. NWSSRP symposium presentation (2020).
- Parsons, M.J.G., Miller, K.J., Thums, M., Gilmour, J.P., Ferreira, L.C., McCauley, R.D., and Meekan, M.G., 2019, Innovation and technology in marine science: AIMS' North West Shoals to Shore Research Program – an update: The APPEA Journal, Extended Abstract, 59, 679–682. https://doi.org/10.1071/AJ18043

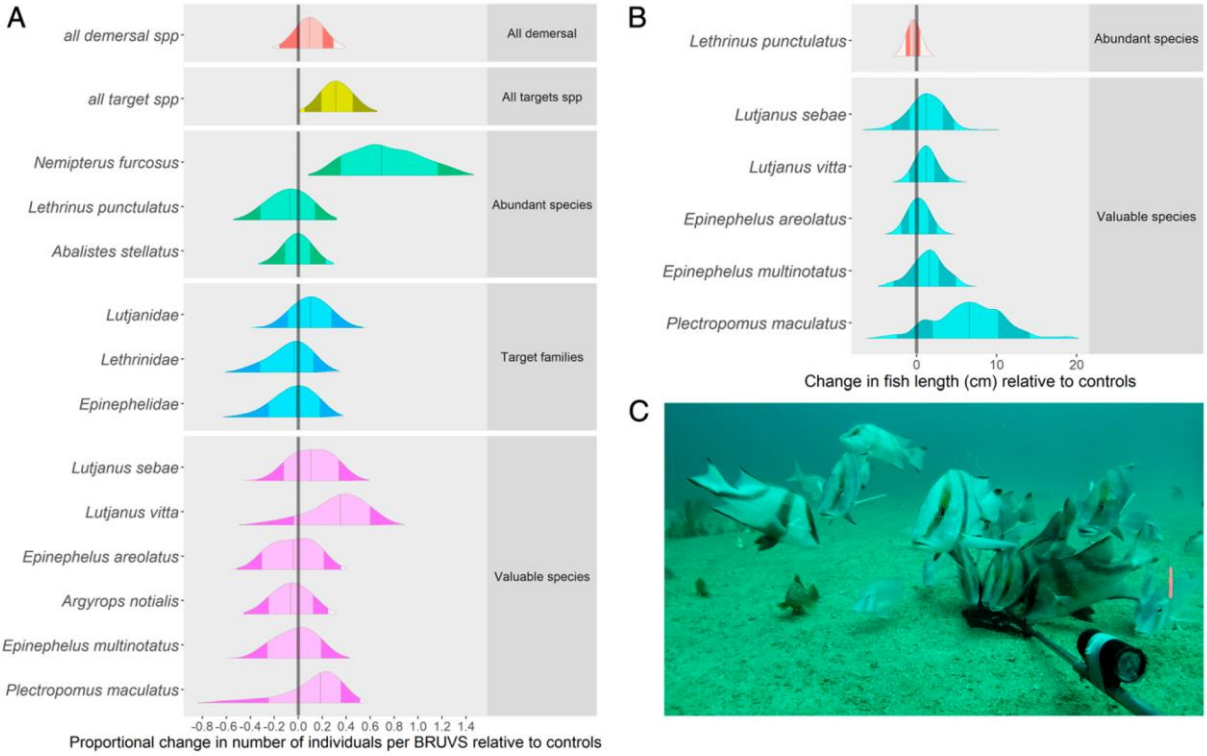


Figure 4. Comparison of the abundance of demersal fishes in high-exposure and control zones following exposure to the seismic source. (A) MBACI posterior distribution plots of all demersal fishes recorded on BRUVS, all species targeted by commercial fisheries, families of commercial importance, and individual species that were of high commercial value and/or abundant. A shift in a distribution above zero (black vertical line) indicates an increase in relative abundance in the high-exposure zone compared with control zones, whereas a shift below zero indicates a decline in relative abundance in the high-exposure zone compared with control zones after seismic exposure. (B) MBACI posterior distribution plots for length of target species observed on BRUVS. A shift in the distribution above zero (black vertical line) indicates an increase in fish length in the high-exposure zone compared with control zones, whereas a shift below zero indicates a decline in fish length in the high-exposure zone compared with control zones. (C) An image captured from a BRUVS video showing a school of red emperor (L. sebae) and surrounding habitat. From [Meekin et al. (2021)](), Figure 3: refer to the paper for the full suite of figures, results and conclusions.