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Effects of 2D seismic on the snow crab fishery

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ABSTRACT

Sound is used by a variety of marine taxa for feeding, reproduction, navigation and predator avoidance and therefore alterations to the soundscape from industrial noise have the potential to negatively affect an animal's fitness. Furthermore, responses to industrial noise would also have the potential to negatively influence commercial fishing interests. Unfortunately marine invertebrates are generally underrepresented in the seismic effects literature. Snow crab harvesters in Atlantic Canada contend that seismic noise from widespread hydrocarbon exploration has strong negative effects on catch rates. We repeated a Before-After-Control-Impact study over two years to assess the effects of industry scale seismic exposure on catch rates of snow crab along the continental slope of the Grand Banks of Newfoundland. Our results did not support the contention that seismic activity negatively affects catch rates in shorter term (i.e. within days) or longer time frames (weeks). However, significant differences in catches were observed across study areas and years. While the inherent variability of the CPUE data limited the statistical power of this study, our results do suggest that if seismic effects on snow crab harvests do exist, they are smaller than changes related to natural spatial and temporal variation.

1. Introduction

Sound is a key environmental feature that is used by a wide variety of marine taxa in many life activities such as navigation, foraging, predator avoidance and communication (Carroll et al., 2016; Edmonds et al., 2016). Noise from marine industries (e.g. seismic exploration, ship activities etc.) alters the soundscape (acoustics scene), and the associated effects on organisms and their responses can influence their physiology and fitness. Moreover, anthropogenic noise may have broader consequences, including the potential to influence important ecological processes (e.g. Solan et al., 2016) and commercial fishing interests (Skalski et al., 1992; Løkkeborg and Soldal, 1993; Engås et al., 1996; Slotte et al., 2004).

Marine environments have experienced increases in exposure to industrial noise in recent decades (Slabbekoorn, 2016). Noise has considerable potential to negatively affect marine organisms both physically and behaviourally and the range of potential effects include death, physical and physiological effects, masking of natural sound, and behavioural responses (Hirst and Roadhouse, 2000; Mooney et al., 2010; Edmonds et al., 2016; Hawkins and Popper 2017; McCauley et al., 2017). Measuring and demonstrating disruptions caused as a result of noise, however, has been challenging (Edmonds et al., 2016).

While the science documenting the implications of anthropogenic noise on marine wildlife is expanding, it remains heavily biased to marine mammals and fishes, whereas other ecologically and commercially important taxa like invertebrates are under-represented (Hawkins et al., 2015; Williams et al., 2015; Carroll et al., 2016). Furthermore, the logistical challenges of conducting marine field studies mean that much of what is known is based on lab studies where realism is difficult to achieve (Popper and Hastings 2009; Hawkins and Popper 2017; Slabbekoorn 2016). Field studies typically lack adequate control sites and/or pre-impact conditions and typically fail to quantify the degree of exposure experienced by the study animals (Edmunds et al., 2016). These complexities and related scientific shortcomings make it difficult to resolve/mitigate resource management conflicts.

Such a situation occurs along the shelf and slope marine habitats of Atlantic Canada where active seismic exploration overlaps extensively with an important snow crab fishery. Since the collapse of the groundfish fishery in Atlantic Canada, snow crab has been the highest valued fishery in Newfoundland and Labrador, with a landed value worth in excess of 273 million dollars (CAD) in 2016 (DFA, 2017). Many snow crab harvesters are concerned about seismic exploration and contend that seismic noise has strong negative effects on catch rates (FFAW personal communication; Christian et al., 2003; Mullowney

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et al., 2014); an issue that is likely to become more acute given that the species is currently experiencing unfavourable environmental conditions in many harvesting areas (DFO, 2016).

Two previous studies (Christian et al., 2003; Christian et al., 2004) attempted to assess the effects of seismic activity on snow crab behaviour, physiology, mortality and catchability and found no effects except for delayed development of embryos. Interpretation of these studies (Christian et al., 2003; Courtenay et al., 2009) note however, that they were challenged by equipment failures (Christian et al., 2003), study design limitations, confounding factors (e.g. delays in embryo development may have been caused by differences in water temperature at the study sites rather than seismic) and questions about the relevance of laboratory studies and field manipulations (Courtenay et al., 2009). Consequently, and not surprisingly, the resource conflict remains unresolved. Recent subject reviews of seismic impacts (Courtenay et al., 2009; Carroll et al., 2016; Hawkins and Popper 2017) have suggested potential ways in which study design, metrics, and topics of interest could improve the confidence in conclusions related to the effects of seismic exploration on marine animals. This study attempts to incorporate these recommendations and improve upon snow crab − seismic investigations by 1) using an enhanced study design with a multi-year BACI approach; 2) improving study realism by recreating seismic/fishery interactions using authentic platforms and methods from the respective industries; and 3) measuring exposures of snow crab to seismic-induced pressure and particle motion using recommended exposure metrics.

2. Methods

To ensure study realism, both industry-based snow crab harvesting and seismic surveying industries were consulted during the study design phase to identify an appropriate study area and methodology that aligned with industry standards. The study sites selected during these consultations were Lilly (control site) and Carson (treatment site) canyons − located on the eastern slope of the Grand Banks (Fig. 1). The sites were selected as they serve as important harvesting areas for snow crab and were within areas that were being actively surveyed by commercial seismic vessels. They were also both characterized by bathymetric relief, enabling an evaluation of potential flight responses to deeper water; a snow crab reaction that harvesters believed to occur following exposure to seismic noise.

The selected study sites were separated by a sufficient distance (70 km) such that Lilly Canyon would be unaffected by seismic air-gun exposures at Carson Canyon. Cumulative noise levels at the control site were similar to or less than the noise level generated by fishing vessels. In each year, all seismic operations were prohibited by the Canada-Newfoundland Offshore Petroleum Board within a 70 km radius of each of our sites for a 1 month period before our controlled seismic exposure and for an additional month at the control site only. This period of quiet-time is based on general observations from the fishing industry which indicate that catch rates are affected for days to weeks but not months. These restrictions were implemented consistently across each study site and used to mark beginning and end points for data analysis.

2.1. Snow crab collections

Catch surveys were conducted by industry harvesters across three trips in each of 2015 (Trip 1: Aug 26–28; Trip 2: Sep 13–16; and Trip 3: Oct 9–12; Fig. 1) and 2016 (Trip 1: Sep 2–5; Trip 2: Sep 18–25; and Trip 3: Oct 17–21) using standard industry survey methods, the Fish Food and Allied Workers (FFAW's) Post-Season Snow Crab Pot Survey (Stansbury et al., 2013). Only one vessel was used for all harvesting activities in each of the years. In 2015, seismic exposure occurred between Trip 2 and Trip 3, whereas in 2016, a scheduled seismic exposure occurred during Trip 2 on September 22. The planned exposure in 2016 enabled an equal distribution of trap sets in "Before" and "After" exposure categories ($n_{\mathrm{Carson}} = 20$, $n_{\mathrm{Lilly}} = 10$; Fig. 2) for each sampling area within the trip (Fig. 1). Sampling intensity in 2016 was guided by power analyses that followed collections of 2015 data (see methods below). Sampling areas were restricted to the area bound by the control and test areas (Fig. 2). Within those areas, trap placement was not random but reflected actual commercial fishing practices. Each sampling location was typically sampled using a string of 10 baited commercial crab traps (5.5 inch mesh) spaced at 25 fathom intervals. Coordinates and depth of water were collected for each deployment and strings were soaked for a minimum of 12 h. All snow crab were counted and crab from the third pot in each string was measured by trained sampling personnel from the Observer Program of the FFAW. Only male crabs were caught during commercial fishing activities.

2.2. Seismic exposure

Each year seismic noise was introduced to the Carson Canyon area from the Atlantic Explorer; an industry seismic survey vessel that is typical of those that operate off Atlantic Canada. The exposure lasted for five days in 2015 (September 25 through the 29th; Fig. 3) when an industrial seismic exploration survey was conducted in and near the study area. The closest approach of the vessel to the sound recorders at the treatment site in 2015 was 1465 m. During 2015, more seismic exploration on the Grand Banks was conducted during our study period outside our 70 km radius buffer zones than in 2016. Seismic exposure on September 22nd 2016 at the Carson Canyon experimental site occurred for a duration of 2 h, and the vessel passed within 100 m from the acoustic recorder. Exposure was also conducted while the fishing vessel was on-site, which enabled experimental fishing immediately before and after exposure. In both years, the seismic source was an airgun array with a total volume of 4880 cubic inches, with shots at 10 s intervals, operated at 2000 psi and deployed at 9 m of depth. The seismic source was modeled using the Airgun Array Sound Model (AASM, JASCO Applied Sciences, MacGillivray 2006). The horizontal zero-to-peak sound pressure level was 251 dB re 1 μPa @ 1 m and the source sound exposure level was 229 dB re 1 $\mu\mathrm{Pa}^2\cdot\mathrm{s}$ @ 1m. The full recorded sound spectrum for 2016, including natural sources such wind, waves and marine mammals is provided in Fig. 4.

2.3. Acoustic measurements

Acoustic recordings were taken at the treatment and control sites from early September until mid-October in both years to 1) ensure that ambient conditions were quiet relative to seismic surveys and 2) confirm that seismic exploration activity at the treatment site was not greater than fishing vessel noise at the control site. The daily sound exposure level was used to compare the sites because it is believed to best capture the effects of long-term sound exposure on marine life (e.g. Popper et al., 2014, [NMFS] National Marine Fisheries Service 2016). The reported sound exposure level is the arithmetic sum of the sound pressure level in the frequency band of 10–7000 Hz over each 24-h period.

Data were collected using an AMAR acoustic recorder (JASCO Applied Sciences), sampling at 16 kHz. The recorders were located on the seabed (105–115 m deep) on frames that held the hydrophones ~0.6 m above the seafloor. In 2015 a Geospectrum M36-V35-100 hydrophone with sensitivity of −165 dB re 1 V/μPa was used; in 2016 an M36-V0-100 hydrophone with sensitivity of −200 dB re 1 V/μPa was used. In 2016 particle motion was also measured. A Geospectrum M20-101 particle acceleration sensor was suspended 0.5 m above the seabed and a PCB-356B18 micro-electrical-mechanical-system (MEMS) accelerometer was coupled to the seabed mooring plate. The close pass of the seismic vessel in 2015 was not planned before the hydrophones were deployed, and the high levels of received sound caused the hydrophone to reach its maximum signal output when the seismic vessel was 8 km from the recorder while operating over the shallow Grand Banks and