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Original Article

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Small effect sizes are achievable in offshore wind monitoring surveys

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Understanding the prospective environmental impacts of offshore wind energy development requires monitoring that allows for adequate testing of conditions for comparison of unimpacted vs. impacted states. A critical component when designing impact studies is determining the required sampling needed to statistically measure a difference between before and after states in the system, which is often challenging because there are little observational data available for the system of interest at the proper spatiotemporal scales. Here, we present the survey design with power and effect size analyses that were used to design a before-after gradient survey to assess American lobster impacts from an offshore wind submarine cable installation in coastal United States waters. By leveraging long-term monitoring data collected from a random-stratified sampling design survey, a gradient survey testing for effects on lobster at distance intervals from the cable using similar sampling methods was developed. Generalized linear mixed models were employed to determine the needed sampling frequency to assess varied catch-per-unit-effort impacts. We present the survey design and our findings from the power analyses to serve as an example of methodology for designing before and after impact surveys for offshore wind energy, and how preexisting data may be used to do so.

Keywords: American lobster, before-after-gradient, offshore wind, power analysis, ventless trap survey.

Introduction

Offshore wind development is expanding rapidly in the United States, with 29 leases currently issued on the Atlantic Coast at this time (BOEM, 2023). However, there is relatively little understanding of how marine ecosystems of the US Atlantic will be impacted by this development. Evaluating the effects and impacts of offshore wind development on local and regional ecosystems has been and will likely continue to be challenging given the ongoing changes in these ecosystems under climate change. Historically, impact location-only, control-impact, and before-after-control-impact (BACI) studies have been used to assess wind development impacts (Methratta, 2020), with BACI being the most comprehensive approach. In a BACI design, an impact site is selected (e.g. a wind farm) and one or more control locations are identified for sampling, which occurs before and after disruption (e.g. construction or operation of a wind farm) (Green, 1979). The "impact" caused by the disruption is measured by testing whether the interaction between the sampling time period and treatment is significant. However, this method fails to allow for the evaluation of changes in spatially explicit relationships over time. Previous studies evaluating wind turbine impacts that included proximity to wind turbines in their sampling design have found that effects depend on distance from the turbines (Wilhelmsson *et al*., 2006; Bergström *et al*., 2013; Van Hal *et al*., 2017; Methratta, 2020; Buyse *et al*., 2022).

Alternatively, the before-after-gradient (BAG) design allows for the measurement of changes in variables of interest as the distance from the disturbance varies (Brandt *et al*., 2011, 2018; Methratta, 2020). BAG studies sample along a gradient with increasing distance from the impact area both before and after disruption, attributing variance due to distance from the turbine to the main effect in the statistical model. This approach is also able to overcome some of the shortfalls associated with BACI designs, primarily the challenge of identifying a suitable control site, which is not needed with gradient sampling (Ellis and Schneider, 1997; Methratta, 2020). Moreover, BAG sampling may also increase the statistical power by including distance from disruption as an independent variable, rather than it being part of the error term (Methratta, 2020).

Ensuring that the proposed survey will achieve a level of statistical power that can detect effects at a desired level is of equal importance to the survey design itself (Kumle *et al*., 2021). Power analyses are often used to inform the sample size to detect the effects of interest (Methratta, 2020). The effect size, defined here as the strength of a relationship between variables, should be determined based on the specific variables and indices to be measured (ROSA, 2020). Prior to conducting any work, researchers usually have a limited understanding of the size of the effect that the study is focusing on. Johnson *et al*. (2015) contend that this is not a problem for conducting a power analysis because studies should be powered to detect the smallest effect that is biologically consequential, which can be an arbitrary determination. However, if there is high uncertainty about how species may be affected, smaller effect sizes have been recommended (ROSA, 2020).

Electromagnetic fields (EMF) from submarine cable installation are one of several aspects of offshore wind development where the anticipated ecosystem effects are unknown. Habitat disruption from cable installation can include physical disturbance and increased turbidity, pollution, and noise, typically considered short-term impacts (BOEM, 2022). EMF, however, are generated for the life of the operation and are thus considered a long-term impact, despite uncertainty regarding the impacts of EMF on most marine fauna (Taormina *et al*., 2018). Physical disturbance to benthic habitats during

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installation or cable mattressing will directly affect the species utilizing such habitats, while EMF may affect resident species and those transiting through the area. As a result, studies assessing exposure to EMF should consider species movement ecology (Hutchison *et al.*, 2020a).

Recent concerns about habitat effects and EMF impacts from offshore wind cable installation have been identified by stakeholders for cables planned to enter Rhode Island (USA) waters into the Narragansett Bay estuary (Figure 1). The Revolution Wind Farm, to be installed in federal waters ∼15 nautical miles southeast of the Rhode Island mainland, will include two high-voltage alternating current cables from the offshore wind farm through federal and state waters to Quonset Point, Rhode Island through the West Passage of Narragansett Bay (VHB, 2022). When state regulators presented a proposed cable corridor in state waters for Revolution Wind to install cables within, the Rhode Island fishing industry expressed concerns about habitat and EMF effects along the proposed route for American lobster (*Homarus americanus*) and Jonah crab (*Cancer borealis*), two species commercially harvested in Rhode Island. Considerations for EMF impacts on these species are warranted based on previous research identifying behavioural and physiological responses to EMF for crustaceans; specifically, both American lobster and *Cancer pagurus,* which is closely related to Jonah crab, have been found to have altered behaviour due to EMF (Scott *et al.*, 2018; Hutchison *et al.*, 2020b). However, most studies evaluating EMF effects on crustaceans have taken place in a laboratory setting and expose organisms to constant EMF, which may not be representative of prospective exposure in the natural environment when cables are installed. Given that EMF from marine renewable energy devices may affect crustaceans behaviorally and physiologically, benthic invertebrates studied in field conditions should be focal species for future EMF work.

The Jonah crab and American lobster are benthic crustacean species that are targeted by trap fishermen in southern New England. Both species' fisheries are significant contributors to Rhode Island's commercial fishing economy, with 2017–2021 average ex-vessel values of $10.65 million for lobster and $3.69 million for Jonah crab (4th and 8th among commercial fisheries in the state, respectively). Given the value of both species to the state and concerns about potential sensitivity to EMF, the fishing industry requested a BAG sampling design be conducted that allows for assessing the impact on lobsters and Jonah crabs from this cable installation using a ventless trap survey. As part of this proposal, there was significant industry interest not only in the survey itself but also in ensuring the ability of the survey to detect impacts at a level that they deem to be impactful to the ecosystem and the fishery. While such impacts are often challenging to test given the lack of data to inform an impact assessment, a pre-existing ventless trap survey employing a random stratified sampling design whose sampling domain includes the cable route of interest was available to conduct a thorough power analysis. Here, we outline the development of the ventless trap BAG-design survey (hereafter termed the cable ventless trap survey) put forth to monitor these species along the cable route. Specifically, we offer a method that leveraged similar survey data of this system to conduct a power analysis, which was ultimately used to guide the survey's sampling and temporal frequency. In doing so, we aim to provide a model for both testing for ecological impacts to cable installation using a BAG design and the value of leveraging preexisting long-term monitoring data to support power analyses for future proposed offshore wind monitoring projects.

Methods

Study location

As part of the Revolution Wind offshore wind farm project, two submarine high-voltage alternating current cables are proposed to be installed in federal waters offshore within the renewable energy cable corridor as described within the Revolution Wind Farm Construction and Operations Plan (VHB, 2022) (Figure 1). These cables will deliver 400 megawatts (MW) of renewable energy to the state of Rhode Island and 304 MW to the state of Connecticut from the Revolution Wind Farm, a joint venture between Ørsted and Eversource. The cable route passes to Quonset Point from the offshore wind farm through federal and Rhode Island state waters (Figure 1). These waters provide habitat to a variety of commercially, ecologically, and culturally valuable fish and invertebrate species.

The objective of this study is to evaluate the spatial and seasonal patterns of relative abundance of lobsters and Jonah crabs in the area before, during, and after construction, with EMF exposure in mind. In assessing EMF effects, field studies are superior because they can assess EMF effects at true scales of influence and responses directly related to species ecology (Hutchison *et al.*, 2020a). In addition, the study will classify the demographics of the lobster and Jonah crab resources (as well as any bycatch), including size structure, sex ratios, moult condition, reproductive status, and shell disease. Pre-construction data collected in this study will be used to assess whether detectable changes occur in the presence, relative abundance, or demographics of lobster and crab resources during and after construction. Since the EMF produced by the cables will decay as distance from the cables increases (Figure 2), a BAG ventless trap survey design is being implemented to collect pre-, during-, and post-construction data on lobster and crab resources in and around the proposed Revolution Wind cable corridor.

Baseline data for power analyses

For monitoring relative abundance changes in American lobsters and Jonah crabs, a ventless trap survey design was utilized. Lobsters are preferentially distributed in structured habitats with cobble and boulders (Wahle and Steneck, 1991), and Jonah crabs are associated with rocky, inshore habitats, as well as muddy substrates on the continental shelf (Jeffries, 1966; Krouse, 1980; Wenner *et al.*, 1992; Truesdale *et al.*, 2019). Lobster's structure-oriented nature has often made mobile gear sampling non-ideal for monitoring the species and has led to the development of standardized sampling using ventless lobster traps (McManus *et al.*, 2021). Since 2006, ventless trap surveys using a random stratified survey design have been conducted in coastal New England states (from Maine through Rhode Island) collaboratively between the state agencies and the commercial fishing community to derive relative abundance indices for lobsters in state waters for use as model inputs in regional stock assessments (Atlantic States Marine Fisheries Commission, 2020; Pugh and Glenn, 2020; McManus *et al.*, 2021).

The Rhode Island ventless trap survey (RIVTS) monitoring Rhode Island state waters administered by the RI Department of Environmental Management, Division of Marine

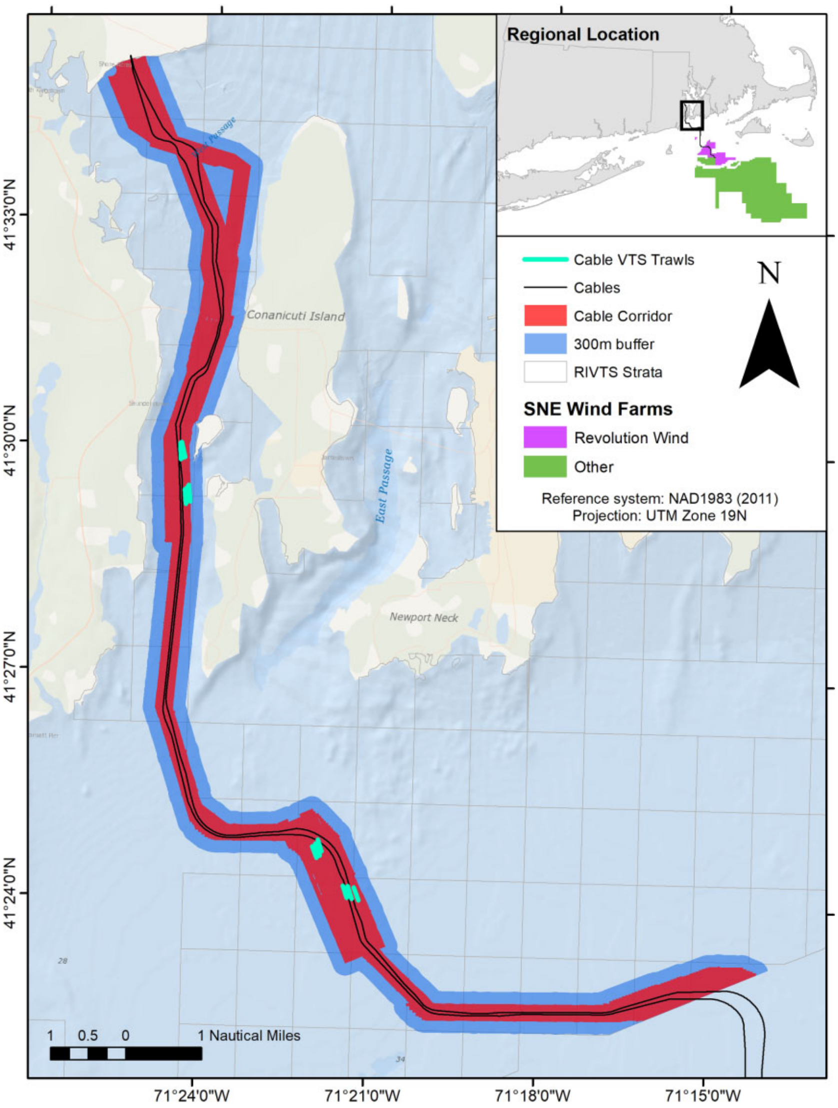

Figure 1. Rhode Island state waters renewable energy cable corridor and proposed high-voltage alternating current cable locations; final locations will be determined during cable burial. Cable Ventless trap survey (VTS) station locations and trawl lines, as well as the ventless trap survey trawl locations as of January 2023.

Fisheries intercepts both lobsters and Jonah crabs. The cable route survey's sampling domain also includes the region of the proposed cable route in state waters, which provides the unique opportunity of having a dataset available for deriving power analyses for additional surveys. These RIVTS baseline data are considered comparable to cable-specific data collection and analysis and enable a robust power analysis to inform the survey design. Based on recommendations from BOEM's renewable energy fishery guidelines (BOEM, 2013) and stakeholders, the cable route survey will quantify preconstruction data for lobster and Jonah crab in the Revolution Wind cable route, such that changes in the resource due to construction and operation of the wind farm can be evaluated (McCann, 2012; Petruny-Parker *et al.*, 2015; MADMF, 2018; ROSA, 2020).

Survey design/procedures

Fieldwork takes place aboard two commercial fishing vessels with scientists onboard to process the catch. The collaboration between scientists and industry allows for a successful, transparent survey that leverages both entities' knowledge bases. As previously noted, the study is being conducted using a BAG experimental design for direct effects, where samples occur along a spatial gradient with increasing distance from the cable. The use of a BAG design eliminates the need for identifying representative control areas and allows for assessing spatial scale. Distance can be incorporated as an independent variable in analyses to explore changes in spatial relationships over time (Methratta, 2020).

For the cable VTS, sampling occurs twice per month at four general locations along the cable route (Figure 1); locations were selected based on depth strata, habitat type, and fishing industry input. The fishing industry's knowledge was essential in avoiding gear conflicts and evaluating substrate complexity to ensure that suitable lobster habitat would be sampled. Habitat type is also recorded for each trawl at the time of setting based on the vessel's depth sounder. Sediment type was also considered in the selection of sampling locations; harder substrates may be associated with a lower likelihood of cable burial achieving target depth. Cable crossings will also result

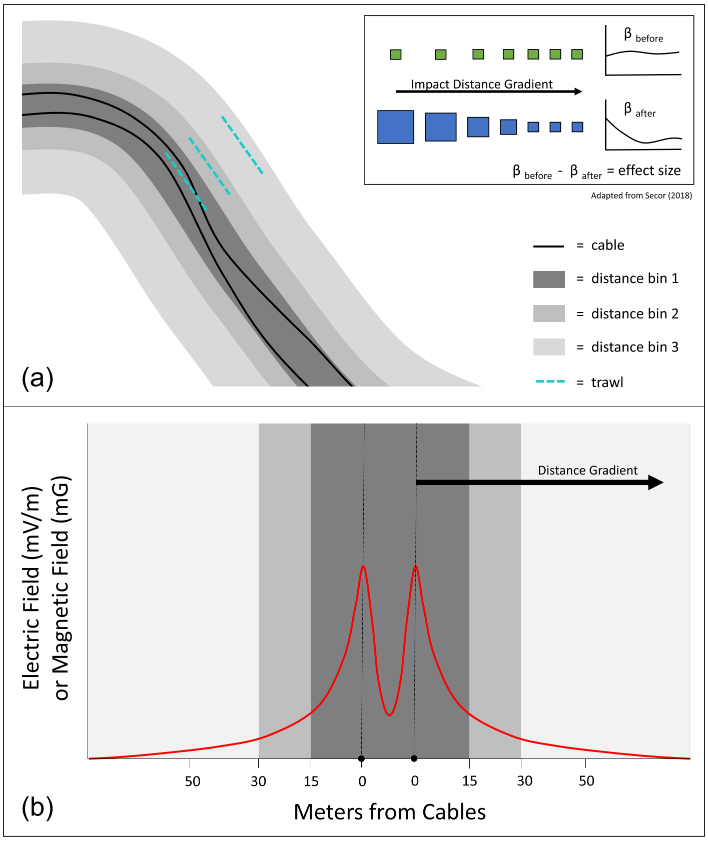

Figure 2. (a) Sampling design schematic showing an example of a single station, with three trawls in different general distance bins. (b) Expected EMF signal shape (electrical and magnetic field) and distance bins used to inform sampling design based on modelling of the Revolution Wind Farm cable plan (see Exponent, 2021).

in cables being laid over existing cables and then covered with cable protection. Areas where cables are not as deeply buried or are crossing other cables will be covered with concrete mattresses, but EMF may be stronger (Normandeau Associates Inc *et al*., 2011).

The sampling design incorporates both ventless and vented lobster traps, consistent with the RIVTS (McManus *et al*., 2021). Each trawl comprises twelve traps, alternating between ventless traps, which have no escape vent for sublegal lobsters and crabs, and vented traps, which have escape vents designed to mimic commercial lobster traps. The incorporation of vented traps into the study design was upon suggestion by industry members who wanted to be able to compare catch rates between survey traps and the commercial fishery. Two types of vented traps are used for the study to allow for comparison between commercial traps targeting crab and those targeting lobster; rectangular vents are favoured for lobster fishing, while circular vents are preferred for targeting crab. Thus, each trawl includes three traps with a double circular escape vent (2 5/8 in, or 6.7 cm, diameter), as well as three traps with a rectangular escape vent (5 $\frac{3}{4}$ by 2 in, or 14.6 by 5 cm). Trawls include two clusters of six alternating vented and ventless traps, with 80 feet (∼24 m) between traps and 360 feet (∼110 m) between the two clusters. Within the clusters, only one type of escape vent is present.

Three twelve-trap trawls are laid parallel to the cables (to the extent practicable) with the first trawl set between the two cables (or as close to the two cables as possible); the two additional trawls are set in parallel from the first trawl (Figure 2). For the purposes of power analysis, the trawls set closest to the cables serve as the impact distance bin. The trawls at a 15–30 m distance serve as the medium gradient. The trawls 30–50 m or more from the cables serve as the largest gradient because beyond 50 m is situated outside the expected EMF signal or sediment plume. The arrangement of sampling points along the spatial gradient in a BAG design should be guided by the research questions of interest (Methratta, 2020). Since EMF densities decay as the distance from the cable increases, these distances were selected based on modelled EMF outputs from the proposed cable design outlined in the Revolution Wind Construction and Operations Plan. The Revolution Wind Farm Export cable configuration used for modelling included two 275 kV AC cables (3-core SLPE 10.4-inch outer diameter), with a minimum of ∼5 m between the two cables. The magnetic field extends to just under 15 m, while the induced electric field extends beyond ∼30 m under the modelled scenario (Exponent, 2021). Setting trawls at the correct distance bins will come with some level of error; however, the survey will leverage the expertise of the commercial fishing captain to get as close as possible. Further, Methratta (2020) notes that more than 2–3 distance categories are needed to properly evaluate the spatial scale of effects beyond just a coarse exploration. Consequently, the start and end coordinates of each trawl are recorded in the cable route survey, allowing for the calculation of individual trap locations and distance (nearest neighbour) from the cables once they are installed; this will generate a larger number of trap distances for analysis.

The study also incorporates a tagging element to evaluate whether lobsters will cross the cables. Fishing industry participants expressed concerns that EMF from the cables may create a barrier to movement. Hutchison *et al.* (2020b) suggested such a barrier does not occur for a high-voltage direct current cable in the Long Island Sound; however, this cable laying includes two high-voltage alternating current cables. Sampling sites are situated on both sides of the cables, and tagging takes place at all four locations. A subset of lobsters, up to ten per trawl, and individuals over 40 mm in carapace length are tagged using Floy anchor tags inserted with a hypodermic needle [as done by Courchene and Stokesbury (2011)]. The anchor tags are retained during moulting and contain a unique identification number and a phone number for reporting recaptures. Locations of tagged lobster releases and recaptures in this or concurrent field sampling programmes are recorded, as are any locations reported through commercial or recreational harvest.

Proposed cable VTS data analysis

The cable ventless trap survey is providing pre-construction data on lobster and crab resources in the proposed cable route. The pre-construction monitoring data will be used to evaluate the spatial and seasonal patterns of the relative abundance of lobsters and Jonah crabs in the area. The BAG survey design with sampling at increasing distances from the cables may also allow for the characterization of the pre-construction community structure of fish species associated with the cable area while examining the spatial scale of impacts on the surrounding habitat and associated fish species. Sampling during and after construction allows for the quantification of any changes in the relative abundance and demographics of the lobster and crab resources.

Analysis of the pre-construction data will be performed in accordance with the BOEM fishery guidelines (BOEM, 2013). The spatial distribution of the lobster and crab resources will be assessed for both years of pre-construction monitoring. Catch per unit effort statistics will be summarized for both lobsters and Jonah crabs, and length frequency distributions will be examined. Catch rates and length frequency distributions will also be provided for tautog (*Tautoga onitis*), black sea bass (*Centropristis striata*), and scup (*Stenotomus chrysops*). Regression tools, such as generalized linear mixed models (GLMMs), will be used to examine the influence of independent variables on the catch rates and distribution of lobsters and Jonah crabs. Results may be compared alongside RIVTS data to address the representativeness of regional trends. Data on power transmission rates (e.g. daily average voltage) through the cables and EMF measurements will also be required annually from Ørsted after the wind farm is operational. These data may also be included in various models as covariates, along with trap distance from the cable and environmental data. Daily average voltage will be included as a model covariate to assess whether any observed changes in catch near the cables correspond to changes in EMF exposure. Locations of tagged lobster releases and captures will not be evaluated using the same approach, as the data do not follow the same BAG methodology. This dataset will be used to determine if tagged lobsters are being caught on the opposite side of the cable that they were released on after the cable is active, as well as to compare lobster movement patterns before, during, and after cable installation and operation if the data allow.

Power analysis simulations

A GLMM approach was targeted because of the model's ability to include the specification of main effects and their interactions (fixed effects), as well as the specification of parameters associated with the variance and correlation of random factors (Matuschek *et al.*, 2017). Mixed modelling approaches also allow for distance from disturbance to be included as one of the main effects in the model (see Petersen *et al.*, 2004; Brandt *et al.*, 2011, 2018 for examples). Since GLMMs can capture multiple sources of random variations, power analyses need to be able to account for this added complexity (Kumle *et al.*, 2021). As such, a simulation approach was used to test for an acceptable sample size at which differences can be detected between sampling groups given variances from existing RIVTS data to inform the survey design. The RIVTS data were ideal for power analysis because they were collected from the same general area, used the same gear, and targeted the same biological indices as the proposed survey. Simulations were conducted to determine a sample size that could achieve a power level of 0.9, with a 0.1 effect size at a 0.05 significance level. A 0.1 effect size, meaning a 10% change in the mean abundance, was targeted because the fishing industry had noted that past offshore wind fisheries monitoring surveys had used larger effect sizes. For example, the South Fork Wind Farm power analysis for their BACI design ventless trap survey evaluated the smallest interaction effect size of 0.19, with a power of 0.8 and significance level of 0.1 (South Fork Wind, LLC and INSPIRE Environmental, 2020). However, fishing industry participants viewed a 10% change in abundance as largely problematic.

Power analyses were focused on assessing changes in the relative abundance or catch of American lobster. While Jonah crabs are frequently intercepted in the RIVTS and of interest for the BAG study, the original RIVTS, which the power analyses herein were based on, was developed explicitly for assessing relative abundance changes for lobster. More specifically, the stratification of the survey was based on previous exploratory work on factors significant in explaining ventless trap catch rate variability for lobsters in Massachusetts (Pugh and Glenn, 2020). The RIVTS sampling season is also more favourable for lobster catch than Jonah crab, for which the fishery peaks in the winter.

Data subsetting

Vented and ventless data were analyzed independently due to differing variances in the baseline datasets. Using R software (R Core Team, 2023), existing RIVTS data from 2006 to 2020 were subsetted to include only ventless lobster traps in one dataset and vented traps in the other, with the number of lobsters per trap as the target metric. To refine the datasets to only samples collected near the proposed cable route, a proximity analysis was conducted in ArcGIS (ESRI, 2023). Sample sites within 300 m of the cable corridor over the entire time series were selected for further analysis in order to refine the data and analyses to those, which most reflect the region proposed for sampling. This resulted in a dataset of 37 sampling sites with 218 trawls between 2006 and 2019, comprising vented and ventless traps; 652 trap catches were available for each vented and ventless traps.

Data simulation

Beginning with ventless trap data only, sampling with replacement (*sample* function in R) was used to randomly expand the spatially subsetted RIVTS ventless trap data to exceed the maximum possible sample size for ventless traps (maximum of 6 traps/trawl $*2$ trawls/month/site $*$ 3 distance bins $*$ 4 stations $*$ 12 months/year $*$ 7 years $=$ 12096 traps). For further analysis, it was assumed that 4 stations would be used, each with 3 distance bins. Ten sample sizes were tested: 501, 1002, 2001, 3000, 4002, 5001, 6000, 7002, 8001, and 9000. Sample sizes needed to be divisible by three to ensure equal sampling across distance bins (i.e. a sample size of 501 equates to 167 traps per distance bin). For each sample size, 1000 model simulations were conducted.

For each individual model simulation, a random sample of the target sample size was pulled from the full resampled dataset; the sample was stratified by four depth bins, used as a proxy for stations. The data were then stratified further into three groups, one for each distance bin (a column was added to represent the respective distance bin from the impact area or cable route). Finally, simulated catch data were generated to test whether a hypothetical effect from the cable could be detected. Data in bin 1 were reduced by 10%, simulating an effect size of 0.1. Data in bin 2 were reduced by 5% since the EMF signal is expected to weaken as distance from the cable increases. Distance bin 3 catch was unmodified.

This process was repeated using the vented data, with the understanding that the expected sample size for the vented traps would be lower than that of the ventless traps. This assumption is due to the two different types of vents employed to target lobster vs. crab, with three traps of each type on each trawl (while there were six ventless traps per trawl). No power analysis was conducted for the traps with circular vents because there are no corresponding RIVTS data.

Analysis

For each of the 1000 simulated datasets per sample size, the simulated data were analyzed using a negative binomial, zero-inflated GLMM because the variance exceeded the mean in the dependent variable, indicating overdispersion. Simulated catch (number of lobsters) per trap was the dependent variable (rounded down to the nearest integer), and the distance bin was the independent, fixed effect variable. Sampling station, year, and month were included as random variables to account for random variability associated with seasonality, location, and year. The R *glmmTMB* package (R Core Team, 2023; available at https://github.com/glmmTMB/glmmTMB) was used to run the following model, where CatchNum refers to the simulated catch:

$$model < -glmm\,TMB\begin{pmatrix} CatchNum \sim Dist\_bin + (1|Station) + (1|Year) \\ + (1|Month)\,, \\ data = sim\_dat, ziformula =\sim 1,\ family = nbinom2 \end{pmatrix}.$$

GLMMs do not provide meaningful *p*-values for model covariates. As such, a likelihood ratio test was used to get a *p*-value associated with the distance bin covariate by testing model significance against a model without distance included as a covariate. The *p*-value was exported to a table containing sample size, simulation number out of 1000, and *p*-values for all models conducted.

Following the completion of model iterations, the proportion of significant *p*-values (defined as cases in which the null hypothesis was rejected with 95% probability; *p*-value $\leq$ 0.05), relative to the total number of iterations per sample size was calculated. This proportion was interpreted as the statistical power, as described by Kumle *et al.* (2021). Power curves are often useful to evaluate relationships among sample size, power, and effect size (see Castelloe, 2000; Krzywinski and Altman, 2013; Lu *et al.*, 2017; ROSA, 2020). As such, power curves for three effect sizes (0.2, 0.1, and 0.05) were plotted to explore the relationships between sample size and power for vented and ventless traps.

Results

Currently, it is unknown whether EMF impacts to target species (i.e. lobster) are the same across depths, locations, and seasons. The data simulation process utilized here assumes that these impacts are equal, independent of time of year or location. Additionally, the data used to conduct the simulations are exclusively summer data (there are no fall or spring samples included). Therefore, the variance of the lobster catch data to be collected year-round may differ from that of the data used for power analyses.

The GLMM simulation approach assumed 3 distance bins and 4 stations. For the original target effect size of 0.1, a sample size of 2001 traps overall achieved a >0.9 statistical power level for vented (0.92) and ventless traps (0.94), which were simulated independently (Figure 3). The current design of 12096 ventless and 6048 vented traps will achieve greater than target power levels: A 5% change in catch will be detectible at greater than a 90% power level, with 95% confidence.

Discussion

A BAG survey was designed that will achieve target power levels; a 10% change in catch after the implementation of offshore cables will be detectible at a 0.05 significance level. The robust survey design implemented in Rhode Island state waters to monitor lobsters and Jonah crabs was enabled by having RIVTS data to conduct a power analysis. It is recommended that power analyses be run using data from the general area, collected using similar gear, and targeting the same biological indices (ROSA, 2020). While methods to simulate data from a model exist [e.g. Barry *et al.* (2017)], the RIVTS data offered a unique opportunity to design a statistically powerful survey because the data are from the actual study area, were collected using the same trap configurations, and were meant to monitor the local abundance of both lobsters and Jonah crabs. Moreover, the continuance of the RIVTS survey along with the cable monitoring study will allow for both datasets to be used in conjunction with one another for addressing various research questions beyond the impact study questions outlined above.

This study benefitted from having prior knowledge of the target cable locations long before the cables are to be installed. One of the primary challenges with the BAG designs is that they require knowledge of the exact locations of construction siting far enough in advance to allow for baseline data collection along a spatial gradient (Methratta, 2020). For this particular study, the proposed cable locations were known multiple years prior to construction, which allowed for survey design to occur far in advance and will enable close to two years of baseline data to be collected. This also allowed for site-specific RIVTS data to be used in power analysis.

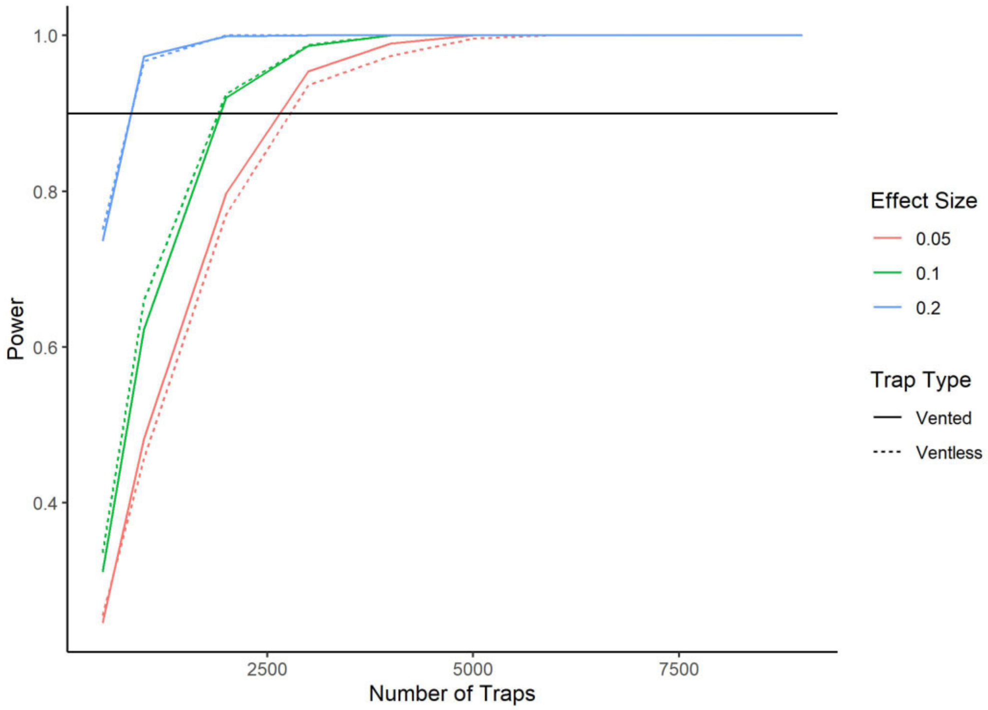

Figure 3. Power as a function of sample size for vented and ventless traps under three effect size scenarios. There are no error bounds around these power curves, as power is calculated as the ratio of model simulations successfully detecting the changes, divided by the total number of simulations. The horizontal line represents the target power of 0.9.

Another unique aspect of the proposed cable VTS survey design is the seasonality of sampling. Most lobster trap studies in southern New England have focused on one half of the year, when lobsters are more abundant in the area (McManus *et al.*, 2021). The RIVTS itself covers June through August annually, while the cable VTS is being conducted year-round. This will offer a rare opportunity to study lobster and Jonah crab abundance and activity throughout the entire year and will provide valuable information for fisheries management, in addition to data for impact assessment and improved understanding of species' responses to EMF. However, it is important to note that there is uncertainty around the catch rates used to derive the power analyses because the RIVTS targets only high catch months for Rhode Island. Therefore, the year-round cable VTS data collected should be used to determine whether summer catch from the RIVTS is a suitable proxy for all seasons.

Existing literature on the effects of EMF on lobsters and crabs suggests that additional work is needed to understand how these species will respond to new cable installations (Taormina *et al.*, 2018). American lobsters and the edible crab (*C. pagurus*) both exhibited behavioural changes in response to anthropogenic EMF. In a lab study, *C. pagurus* demonstrated an attraction to EMF-exposed shelter compared to control shelter and reduced their time spent roaming; exposure also disrupted physiological circadian rhythms (Scott *et al.*, 2018). American lobsters demonstrated a subtle response to EMF from live high-voltage direct-current cables in a field study in the waters off Long Island, New York (USA). The study found that lobsters exposed to the cables' EMF explored the seabed more and climbed their enclosures less than lobsters in control enclosures, signifying increased foraging activity over the cables (Hutchison *et al.*, 2020b). Since the earth's magnetic and electrical fields are used by various species to locate resources, cable EMF may disrupt some species' abilities to locate food. Thus, for both American lobsters and Jonah crabs, the installed cables may have the potential to alter their foraging activity, and consequently their local biomass or abundance. Boehlert and Gill (2010) discuss how translating individual-level EMF effects into assessments of biologically or ecologically significant impacts on populations may be challenging. However, developing a survey that can detect changes in abundance at a fine scale is a step towards understanding whether subtle behavioural changes result in localized population-level effects.

Further, the cable VTS survey does include tagging of lobsters and Jonah crabs, which may allow for improved understanding of species' movements around the cables and within Rhode Island state waters. Similar tagging has been used previously to study lobster movement ecology (Fogarty *et al.*, 1980; Campbell and Stasko, 1986), but no studies have used tagging to study movement in relation to undersea cables. Fishing industry participants have expressed concerns that lobsters may not cross EMF-producing cables. While tagging will not detect fine-scale changes to lobster movements near the cables, sampling stations are situated on both sides of the cable (in addition to other concurrent fisheries surveys), which will allow for intercepting lobsters and determining whether the cables present a barrier to movement. However, this will not be evaluated using the BAG design and no power analysis has been conducted due to an absence of appropriate data. Rather, lobsters will be tagged throughout the study and locations of recaptures when reported will be recorded and evaluated to determine if lobsters are likely crossing over the cables and to determine if their movement patterns changed in response to cable installation (data permitting).

As noted earlier, the power analyses did not address Jonah crab, nor did they include any potential bycatch species such as tautog, black sea bass, scup, whelk (*Busycotypus canaliculatus* and *Busycon carica*), or spider crabs (*Libinia* spp.). High catches may occur for some of these species based on the RIVTS survey data, so it may be possible to assess cable impacts to other species as well. Moreover, these analyses assume the EMF response to lobsters is measurable as catch per unit effort, but did not test for other features (e.g. differences in sex-specific catch, size composition, egg-bearing female encounter rate, and shell-disease prevalence). These features were not included in the power analyses because no literature currently suggests that these other population demographics are affected by EMF. Movement characteristics have been documented to be influenced by EMF (Scott *et al.*, 2018; Hutchison *et al.*, 2020b) but were also not addressed within the power analyses because no data were available to conduct such an analysis. Nevertheless, because these data are being collected through the cable VTS, they could be evaluated as part of the BAG, or other analyses.

Of central importance is that the cable route survey design demonstrates that a 0.1 (and likely 0.05) effect size is achievable with a high level of statistical power (0.9) for monitoring impacts on fisheries resources. Field studies are often disadvantaged by effect size, and subject to an inability to detect ecologically important effects (Franco *et al.*, 2015), usually due to time and cost constraints. Given these constraints, it is not surprising that designs with larger effect sizes and lower power levels have been proposed (e.g. South Fork Wind, LLC and INSPIRE Environmental, 2020). Consequently, these surveys may be unable to detect smaller changes in species abundance or biomass. In fact, some fishery scientists argue that oversampling in the first year of impact monitoring surveys may be needed to ensure sufficient samples are collected (ROSA, 2020). The cable route survey goes further by oversampling for the entirety of the survey, and as a result may detect smaller changes than originally targeted. Oversampling using a fixed gear of multiple traps on trawls where metrics are recorded at the trap level makes collecting a larger number of samples possible. This may not be easily achieved for other gear types, for example, where a sample corresponds to a trawl at one location. Nevertheless, the authors hope this survey may serve as a model for how offshore wind BAG surveys can be conducted and how lower effect sizes coupled with higher statistical power can be achieved.

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Supplementary data

Supplementary material is available at the *ICESJMS Journal* online version of the manuscript.

Conflict of interest

The authors have no conflicts of interest to declare.

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Author contributions

J.L.: Conceptualization, Methodology, Formal analysis, Visualization, Writing—Original draft; C.T.: Conceptualization, Methodology, Writing—Original draft; K.R.: Writing—Review and Editing; and M.C.M.: Conceptualization, Supervision, Writing—Review and Editing

Data availability

The data described and analyzed within this article will be shared on reasonable request to the corresponding author.

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