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## **Cover Page Footnote**

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## Identical Response of Caged Rock Crabs (Genera *Metacarcinus* and *Cancer*) to Energized and Unenergized Undersea Power Cables in Southern California, USA

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Increasingly, energy generation facilities (i.e., wave and wind) are being sited in offshore marine waters. The electricity generated from these facilities is transmitted to shore through cables carrying alternating (AC) or direct (DC) current. If DC is used, it is converted to AC for the North American grid at onshore stations. While these currents produce both electric and magnetic fields, only the magnetic field, here called an electromagnetic field (EMF), is emitted from the cable. Some marine vertebrates and invertebrates can detect EMFs (summarized in Normandeau et al. 2011<sup>1</sup>). However, while it is clear that organisms can detect EMFs, less well understood is how these animals respond behaviorally to this stimulus, and concerns have been raised regarding how these organisms might interact with energized subsea cables<sup>1</sup>. Among fishes, a few field or quasi-field studies have produced what appear to be minor or equivocal responses. For instance, in a study of three species of elasmobranchs held in offshore mesocosms and subjected to EMF, there were some statistically significant differences in behavior; however these differences were inconsistent among individuals within a species<sup>2</sup>. In other studies, migrating European eels (*Anguilla anguilla*) in the Baltic Sea slowed, but did not halt, their swimming speed around an energized cable (Westerberg and Lagenfelt, 2008), and the movement of a number of fish species did not appear to be affected by an energized cable off Denmark<sup>3</sup>.

Along the Pacific Coast of the United States, fishers have also raised this issue<sup>4</sup>; one of the specific issues is how crabs (which form major fisheries along the Pacific Coast) might respond to energized power cables. There have been few studies on the behavioral changes that invertebrates might show in the presence of EMF although a small laboratory study implied that Dungeness crabs (*Metacarcinus magister*) were attracted to

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<sup>1</sup> Normandeau, Exponent, and T. Tricas, and A. Gill. 2011. Effects of EMFs from undersea power cables on elasmobranchs and other marine species. U.S. Dept. Int., Bur. Ocean Energy, Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09.

<sup>2</sup> Gill, A.B., Y. Huang, I. Gloyne-Philips, J. Metcalfe, V. Quayle, J. Spencer, and V. Wearmouth. 2009. COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2. EMF-sensitive fish response to EM emissions from sub-sea cables of the type used by the offshore renewable energy industry. COWRIE Ltd. COWRIE-EMF-1-06.

<sup>3</sup> DONG Energy and Vattenfall A/S. 2006. Review Report 2005 The Danish offshore wind farm demonstration project: Horns Rev and Nysted offshore wind farms environmental impact assessment and monitoring. The Danish Offshore Wind Farm Demonstration Projects.

<sup>4</sup> Pacific Fisheries Management Council (PFMC). 2010. Letter from PFMC to Federal Energy Regulatory Council, dated 19 June 2010. Titled COMMENT Reedsport OPT wave Park Project, FERC No. 12713. Accessed 11 December 2013. [http://www.pcouncil.org/wp-content/uploads/Cmt\\_Reedsport\\_OPT\\_FERC.pdf](http://www.pcouncil.org/wp-content/uploads/Cmt_Reedsport_OPT_FERC.pdf)

a zone of high EMF and that crabs in some zones with elevated EMF levels were somewhat more active than control animals<sup>5</sup>. Needed are studies that address how organisms respond to an *in situ* energized submarine power cable. The presence of energized and unenergized AC submarine cables in close proximity to one another off the coast of southern California allowed us to conduct such an experiment on crabs.

The experiments took place off Las Flores Canyon (34°28'N, 120°02'W), southern California, USA. Here several energized and unenergized submarine power cables, identical in construction, lie unburied on the seafloor and extend to offshore oil and gas platforms (Fig. 1). We selected two cables for this study; one was energized and the other unenergized. The two cables run parallel to each other, perpendicular to shore, and are approximately 7 m apart. Note that in an ongoing study we have determined that the EMF around the energized cable dissipates to background levels at a distance of about one meter.

We used stiff plastic perforated boxes (88 cm x 57 cm x 23 cm) that were secured to the sea floor with sand anchors at a bottom depth of 10 m. Each box was placed so that one end was in contact with one of the two cables. In all, twelve boxes were installed, six adjacent to the energized cable and six adjacent to the unenergized one. The boxes were installed at intervals of 2.5 meters along each cable, half on the east side and half on the west side and these alternated from one side to the other (Fig. 1). To reduce the chances of crabs visually sensing the cable, plastic panels were attached to the end of each box closest to the cable and identical panels were attached to the boxes on the end farthest from the cable. To further reduce the chances that the crabs could sense a difference between the cable end and the noncable end, we also removed the common brown macroalgae *Pterygophora californica* that occurs on the cables but does not live on the adjacent sea floor.

With the boxes in place along the energized and unenergized cables, divers stocked each with one adult crab of either *Metacarcinus anthonyi* or *Cancer productus*, for an experimental trial. Each crab, which was randomly selected from a stock of legal-sized crabs provided by a commercial crab fisherman, was dropped through a hinged hatch, which was centered in the middle of the cage. One hour after emplacement, divers recorded the position of the crab within the box by visually dividing it into two halves, the portion closest to the cable being designated “near-half” and that furthest from the cable “far-half” (Fig. 1). A second diver then opened the box to record EMF values (in microteslas -  $\mu$ T) with a handheld EMF detector (EMF 1390 from General Tools & Instruments). Readings were taken on the floor of each box at the edge closest to the cable and on the floor of that box furthest from the cable. The boxes were then leaving the crab in the box. Divers returned 24 hours later to observe where the crabs were positioned in the boxes and recorded EMF values. The crabs were then removed from the boxes and new, previously untested, crabs inserted for the next trial. Four sequential, 24-hour trials comprised an experiment. A total of four experiments were conducted in 2013 (10–14 June, 9–13 September, 30 September–4 October, and 7–11 October). Crabs were selected randomly for each box. Gender was recorded for each crab with exception of the first experiment.

The primary question we addressed in this study is whether crabs responded differently to the two types (energized and unenergized) of cables. The observations made 1 hour

<sup>5</sup> Wilson, C.S. and D.L. Woodruff. 2011. A preliminary study on the effects of electromagnetic fields on the burial behavior and location of the Dungeness crab, *Cancer magister*. Pacific Northwest National Laboratory, Prepared for the U.S. Dept. Energy, Contract DE-AC05-76RL01830, PNNL-20729.

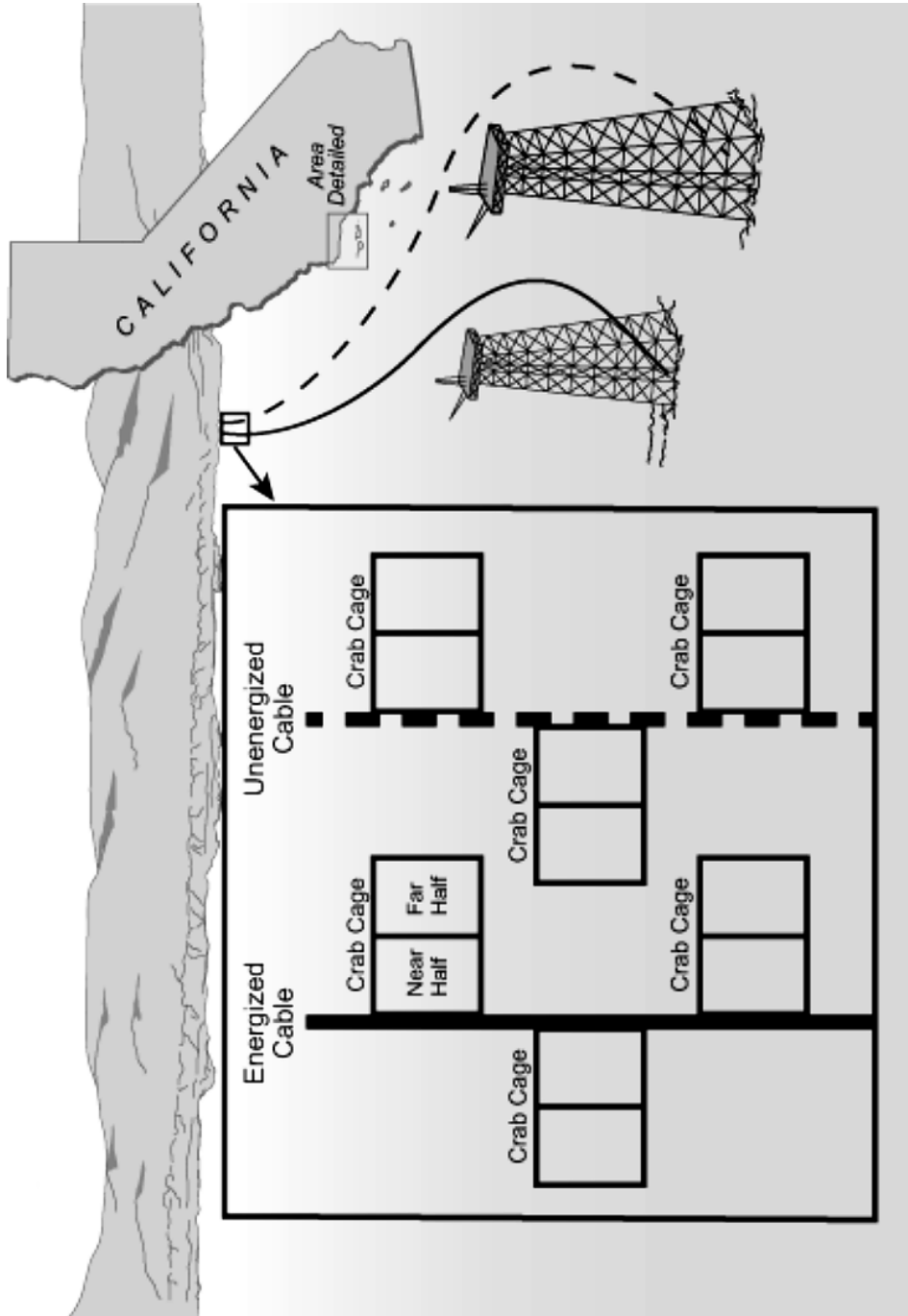


Fig. 1. The location of the energized and unenergized cables used in the experiments and the orientation of six of 12 boxes. The distance between the cables, about 7 m, is not drawn to scale.

and 24 hours after the crabs were set in the cages were evaluated separately. We used the generalized linear model (GLM) approach to determine if crabs along the energized cable were found nearer or farther from the cable compared to crabs along a non-energized cable. A crab's position, in the half of the box near or far from the cable, was the response variable. Given the binomial distribution of the response variable, a logistic regression model was used with a logit link function.

We used JMP software to fit each GLM to the data by Firth bias-adjusted maximum likelihood estimation of the parameter vectors<sup>6</sup>. The most complete GLM model analyzed included the effects of experiment (1–4), trial (1–4) nested within experiment, side of cable that the cage was set (west, east), and type of cable (energized and unenergized) as well as the intercept. A likelihood-ratio Chi-square test evaluated the hypothesis that all the model parameters were zero. We also examined a sequence of simpler GLM models to identify the best-fit model that might include as few as one predictor. Akaike's information criterion (AIC) was used to select between candidate models.

To determine if the genders responded differently to the energized and non-energized cables, we first added gender as a predictor in the complete GLM model using data from all but the first experiment when gender was not recorded. We used the same method above to determine the best-fit model. We also parsed the data by gender to determine if either male or female crabs, separately, responded differently to the two types of cables. Again, we used the same GLM approach described above to determine if cable type alone or with the other explanatory factors had a significant effect on a male or female crab's position in a box.

The EMF at the end of the boxes closest to the energized cable ranged from a mean of 46.2  $\mu\text{T}$  to 80.0  $\mu\text{T}$  during the experiments, and the readings on the far end of the boxes never exceeded 0.9  $\mu\text{T}$  (Table 1). Along the unenergized cable, EMF did not exceed 0.2  $\mu\text{T}$  in the near half or far half of the boxes during the experiments. A total of 192 crabs were used in this study; 24 crabs in each of four experiments on each cable (Table 2). The positions of all 192 crabs were observed 1 hour after emplacement. A total of eight crabs were recorded as lost 24 hours after emplacement during the four experiments; three crabs in boxes along the unenergized cable and five crabs along the energized cable. Escapement was not possible and loss of crabs was likely due to predation by octopuses.

The crabs responded no differently in the boxes along the unenergized and energized cables. Both 1-hour and 24-hours after the crabs were set in the boxes, there were no apparent differences in the proportion of crabs near the two types of cable regardless of the side of cable where the boxes were set (Fig. 2). For a given observation period, experiment, trial nested within experiment, side of cable that the cage was set, and type of cable had no significant effect on the position of crabs in the boxes as evident from the GLM that was not significantly different from the intercept model (1 hour:  $n=192$ ,  $-\log$  likelihood = 5.676,  $X^2=11.351$ ,  $DF=17$ ,  $p=0.838$ ,  $AIC=295.901$ . 24 hours:  $n=184$ ,  $-\log$  likelihood = 7.946,  $X^2=15.892$ ,  $DF=17$ ,  $p=0.532$ ,  $AIC=281.037$ ). None of the GLMs that incorporated fewer explanatory factors could predict with statistical significance the variability in crab responses in the boxes next to the cables one hour or 24 hours after deployment.

The proportion of crabs near the two types of cables 24 hours after deployment was highly variable across experiments regardless of side of the cable the box was set (Fig. 2).

<sup>6</sup> Schwarz, C.J. 2013. Sampling, regression, experimental design and analysis for environmental scientists, biologists, and resource managers. <http://people.stat.sfu.ca/cschwarz/Stat-650/Notes/PDFbigbook-JMP/>.

Table 1. Level of electromagnetic field (microteslas -  $\mu\text{T}$ ) in those parts of boxes *closest* to unenergized and energized cables as read one hour and 24 hours after crabs were inserted. EMF readings at the farthest end of the boxes were  $<0.1\mu\text{T}$  at the unenergized cable and  $<0.9\mu\text{T}$  at the energized cable.

The lower n in experiments 1 and 4 were due to the flooding of the housing containing the EMF meter after the first day of observations, which led to failure of the devices. However, note that the energized cable used in this experiments has been in continuous use for many years and did not fail during the course of these studies.

Experiment	Cable Type	1 hr			24 hr		
		$\bar{x}$	sd	n	$\bar{x}$	sd	n
1	Unenergized	0.0	0.0	6	–	–	0
	Energized	46.2	11.4	6	–	–	–
2	Unenergized	0.0	0.0	24	0.1	0.0	24
	Energized	57.0	7.4	24	55.5	8.7	24
3	Unenergized	0.0	0.0	24	0.1	0.0	24
	Energized	54.2	9.3	24	56.1	0.0	24
4	Unenergized	0.1	0.0	6	0.1	0.1	6
	Energized	80.0	19.7	6	51.0	10.1	6

Combining the observations from the four experiments, the proportion of crabs found close to the two types of cable changed little between the observations made one hour and 24 hours after the crabs were set in the boxes (Fig. 3). One hour after emplacement, 53% (51 of 96) of the crabs set along the unenergized cable and 55% (53 of 96) of the crabs along the energized cable were observed in the near-half of the boxes (Fig. 3). The log-likelihood test of the GLM showed no cable-type effect on crab response ( $n=192$ ,  $-\log$  likelihood=0.042,  $X^2=0.084$ ,  $DF=1$ ,  $p=0.772$ ,  $AIC=270.876$ ). The AIC for this single-factor model indicates that it is no worse fit of the 1-hour data than the GLM of all explanatory factors. In comparison, 24 hours after emplacement 56% (52 of 93) of the crabs set along the unenergized cable and 51% (46 of 91) of the crabs set along the energized cable were in the near-half of the boxes (Fig. 3). Although a slightly greater proportion of crabs were nearer the unenergized cable than the energized cable,

Table 2. Number and gender (F = female, M = males, Unk = unknown) of crabs used in four experiments. Gender of crabs in experiment 1 was not determined. Loss of crabs between one hour and 24 hours was likely due to predation by octopuses.

	Unenergized				Energized				Grand Total
	F	M	Unk	Total	F	M	Unk	Total	
Experiment 1									
1 hr			24	24			24	24	48
24 hrs			23	23			24	24	47
Experiment 2									
1 hr	17	7		24	17	7		24	48
24 hrs	17	7		24	17	7		24	48
Experiment 3									
1 hr	17	7		24	22	2		24	48
24 hrs	15	7		22	19	2		21	43
Experiment 4									
1 hr	18	6		24	17	7		24	48
24 hrs	18	6		24	16	6		22	46

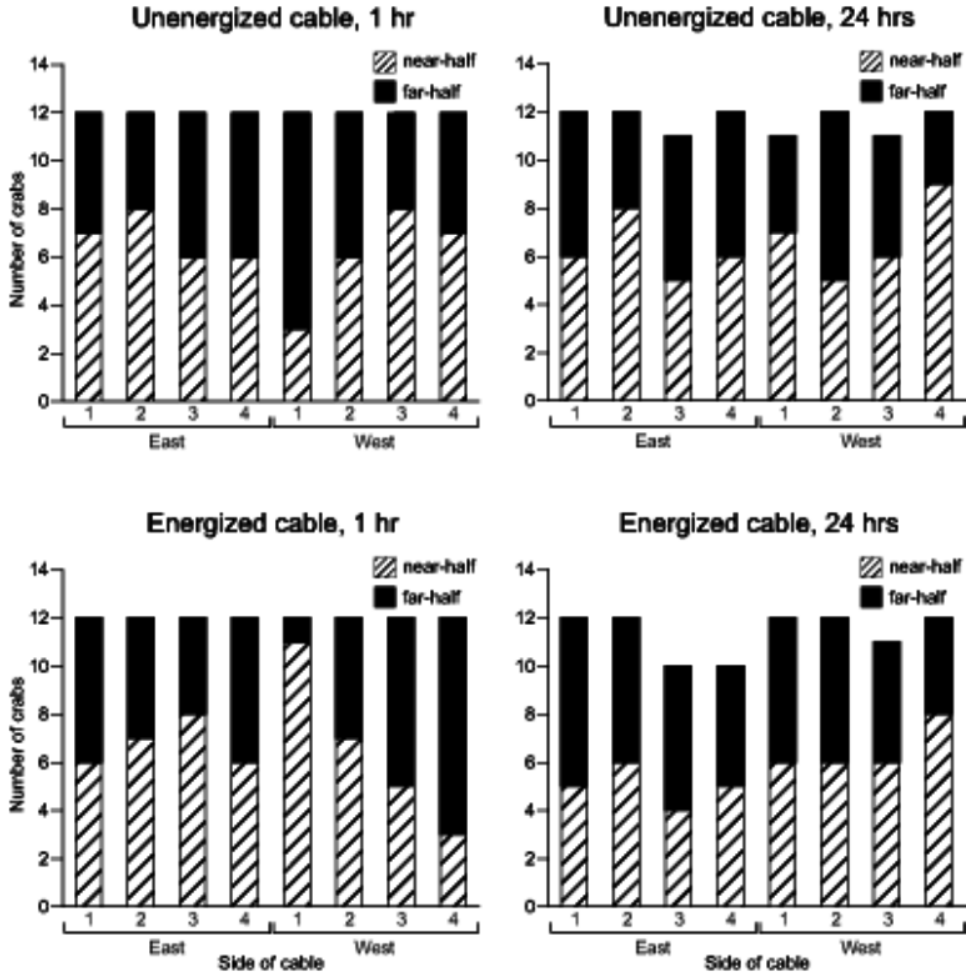


Fig. 2. The number of crabs positioned in the near-half and far-half of boxes on the west side and east side of the energized and unenergized cables by experiment, one hour and 24 hours after deployment.

cable type in the single factor model had no effect on crab response ( $n=184$ ,  $-\log$  likelihood = 0.266,  $X^2=0.5318$ ,  $DF=1$ ,  $p=0.466$ ,  $AIC=259.897$ ). As was the case for the 1-hour observations, the proportion of crabs found close to the two types of cable did not differ 24 hours after the crabs were set in the boxes.

Some of the crabs were found in the opposite half of the box when reexamined 24 hours later. Along the energized cable, 23.1% (21 individuals) of 91 crabs moved to the half of the box that was closer to the cable from the half farther, and 27.5% (25 individuals) moved to the half of the box farther from the half nearer. Along the non-energized cable, 21.5% (20 of 93 individuals) moved to half of the box that was closer to the cable, and 18.3% (17) moved to the farther half of the box. Movement of crabs within the boxes between the one-hour and 24-hour observations is unknown.

The addition of gender to the complete GLM failed no better using data from experiments 2-4 when gender was recorded (1 hour:  $n=144$ ,  $-\log$  likelihood = 6.632,  $X^2=13.265$ ,  $DF=14$ ,  $p=0.506$ ,  $AIC=221.950$ . 24 hours:  $n=137$ ,  $-\log$  likelihood = 7.136,



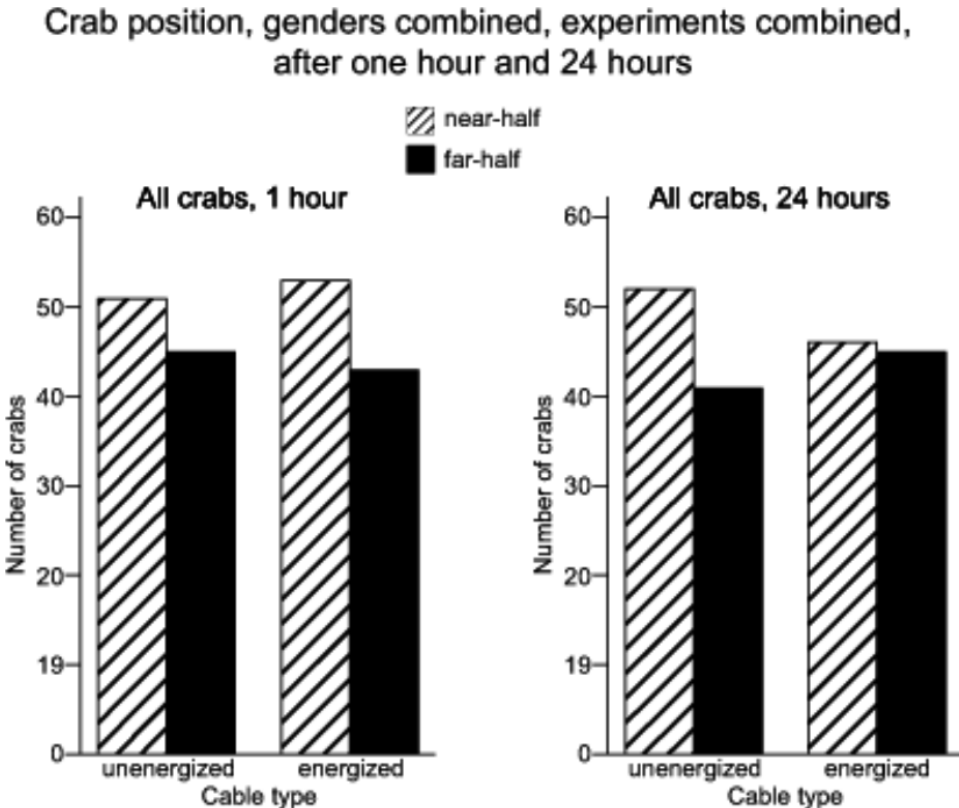


Fig. 3. The number of crabs positioned in the near-half and far-half of boxes adjacent to energized and unenergized cables after one and 24 hours.

$X^2=14.272$ ,  $DF=14$ ,  $p=0.430$ ,  $AIC=211.300$ ). None of the GLMs that incorporated fewer explanatory factors could predict with statistical significance the variability in crab responses in the boxes next to the cables one hour or 24 hours after deployment.

Specifically, cable type had no effect on a crab's position in the boxes regardless of gender (Fig. 4). One hour after emplacement, 54% of the females next to the unenergized cable (26 of 52 crabs) and 50% of the females next to the energized cable (28 of 56) were found in the near half of boxes ( $n=108$ ,  $-\log$  likelihood =0.080,  $X^2=0.160$ ,  $DF=1$ ,  $p=0.689$ ,  $AIC=155.643$ ). Twenty-four hours later, a slightly higher proportion of crabs were found next to both types of cables, 58% of the females (29 of 50 crabs) next to the unenergized cable were found in the near-half of boxes, whereas 52% of the females set along the energized cable (27 of 52 crabs) were in the near-half. Again, the females responded no differently to the two cable types ( $n=102$ ,  $-\log$  likelihood =0.190,  $X^2=0.380$ ,  $DF=1$ ,  $p=0.538$ ,  $AIC=146.285$ ). Males also responded no differently to the two cable types. One hour after emplacement, 65% of the males next to the unenergized cable (13 of 20 crabs) and 50% of the males next to the energized cable (8 of 16) were found in the near half of the boxes (Fig. 4). Although it appears that a greater proportion of males were found nearer the unenergized cable than energized cable, cable type in the single factor GLM had no statistically significant effect on male crab response ( $n=36$ ,  $-\log$  likelihood =0.410,  $X^2=0.820$ ,  $DF=1$ ,  $p=0.365$ ,  $AIC=54.8330$ ). Twenty-four hours

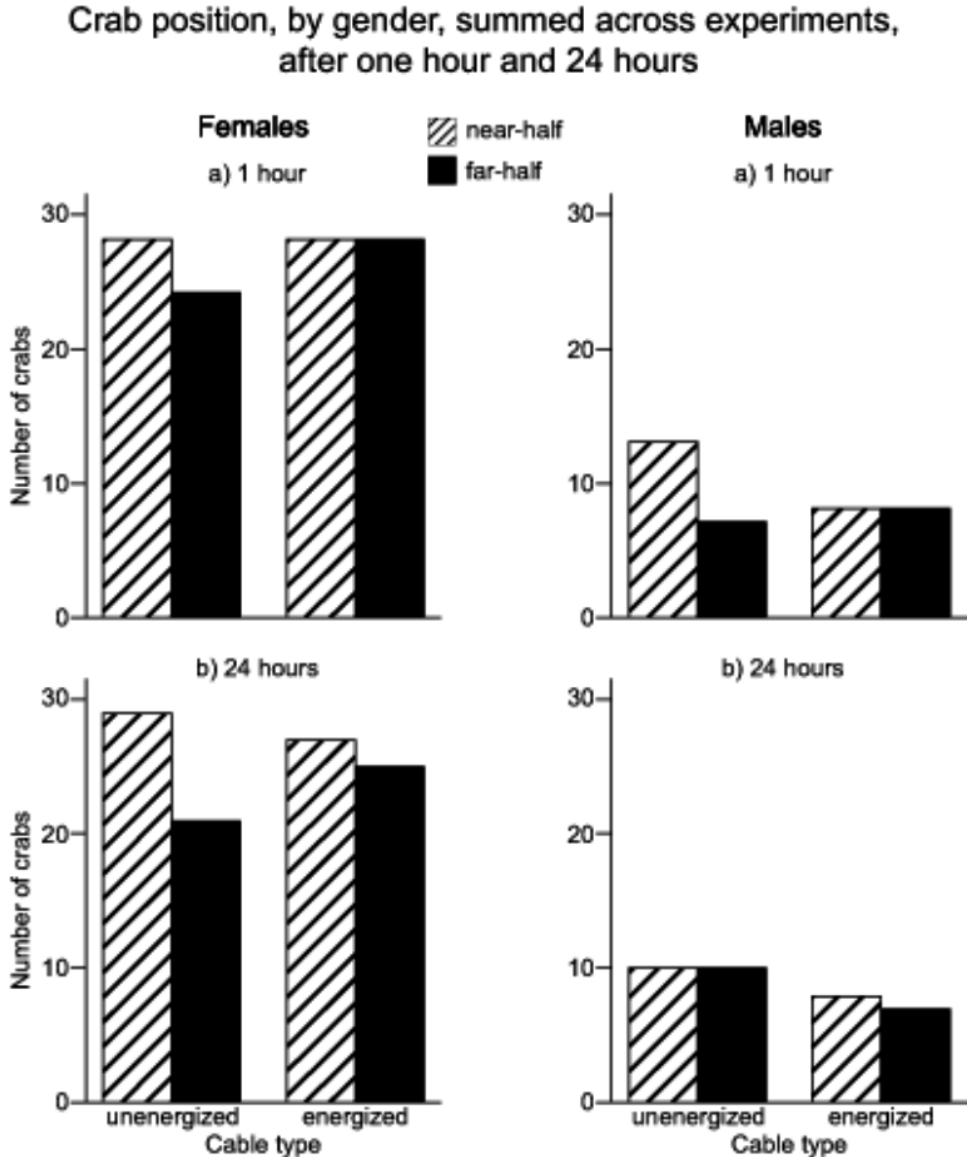


Fig. 4. The number of female and male crabs positioned in the near-half and far-half of boxes adjacent to energized and unenergized cables, one hour and 24 hours after employment.

later, 50% of the males next to the unenergized cable (10 of 20 crabs) and 53% of the males next to the energized cable (8 of 15) were found in the near half of the boxes ( $n=35$ ,  $-\log$  likelihood = 0.019,  $\chi^2=0.038$ ,  $DF=1$ ,  $p=0.846$ ,  $AIC=55.228$ ).

Pacific Coast crab fishers have voiced several concerns regarding crabs and their potential responses to the EMF generated by submarine power cables. These concerns generally relate to whether crabs are either attracted to, or repulsed by, EMF. If either of these occurs, crab migrations might be compromised and, more specifically, crabs might not walk over a cable to reach a baited trap. While this experiment does not address all of

these concerns, it does imply that these two crab species may not respond either positively or negatively to the levels of EMF generated by this specific energized cable.

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