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ABSTRACT

Western gray whales (*Eschrichtius robustus*) aggregate off the northeastern coast of Sakhalin Island, Russia during summer-autumn to feed on benthic and near-benthic prey. During summer 2001, 3D seismic surveys were conducted during a six-week period in known gray whale foraging areas off Sakhalin Island. To test the hypothesis that the distribution of gray whales on the feeding ground would shift away from nearby seismic surveying, we examined the number of whales and number of pods (dependent variables) sighted during systematic scans in relation to three independent variables (i.e. pre-seismic, seismic, post-seismic). Results showed the main effect of condition was significant, with both the number of whales and the number of pods during pre- and post-seismic conditions significantly differing from the seismic condition. Although the relationship between the seismic survey operation period and the observed change in distribution of whales is only a correlation at this time, we strongly believe that it warrants an appropriate management response. The western gray whale population is critically endangered and depends on the northeastern Sakhalin Island feeding ground for the majority of its annual food intake. Disruption of feeding in preferred areas is a biologically significant event that could have major negative effects on individual whales, their reproductive success, and thus the population as a whole.

KEYWORDS: WESTERN GRAY WHALE; SEISMIC SURVEY; FEEDING; DISTURBANCE; CONSERVATION; OKHOTSK SEA; RUSSIA

INTRODUCTION

Western gray whales (*Eschrichtius robustus*) aggregate off the northeastern coast of Sakhalin Island, Russia during summer-autumn to feed on benthic and near-benthic prey

(Würsig *et al*., 2000; Weller *et al*., 2002). Despite considerable past and recent ship and aerial survey effort in the Okhotsk Sea, few gray whale sightings of any appreciable numbers have been reported outside of the northeastern Sakhalin Island area (see Vladimirov, 1994; Berzin, 1990; Weller *et al*., 2002a, 2002b, 2002c). Therefore, the northeastern coast of Sakhalin Island represents the only known feeding ground for the western population (Blokhin *et al*., 1985; Weller *et al*., 1999). Photo-identification studies between 1994 and 2001 in this region show high levels of inter-annual site fidelity and intra-annual return by most whales (Weller *et al.*, 2002b). This habitat use pattern is particularly true for reproductive females that feed in the area during all phases (i.e. while pregnant, lactating, and resting) of their reproductive cycle (Brownell and Weller, 2002; Weller *et al.*, 2002a, 2002b).

Sakhalin Island (Fig. 1) is a region rich with large reserves of offshore oil and gas that, until recently, has been unexploited. There are nine major oil and gas development regions in the waters that surround Sakhalin Island. Two major projects (Sakhalin I [Exxon Neftegas Ltd.] and Sakhalin II [Sakhalin Energy Investment Company] directly overlap or are in near proximity to the primary feeding ground of western gray whales. Activities related to oil and gas exploration and production, including increased vessel and aircraft traffic, geophysical seismic surveys, well-drilling, and production operations are of concern to the well-being of western gray whales summering in the area.

Results from studies on the reactions of cetaceans to underwater noise and other human-related activities are highly variable, ranging from no apparent response to active avoidance (for review see Richardson *et al.*, 1995). Although some studies have documented no or only subtle short-term changes in behavior, it is important to recognize that tolerance of noise does not necessarily indicate that it has no deleterious effects (Richardson and Würsig, 1997). Long-term or cumulative effects of noise and disturbance at the individual and population levels are presently little understood.

Some of the best examples of large whales changing their behavior in response to various sources of underwater noise have come from studies on eastern gray whales (for review see Moore and Clarke, 2002). Changes in surface-dive and respiration behavior, distribution and, in one case, complete abandonment of a known wintering area, in relation to increased anthropogenic activity and associated noise have been recorded

(Bryant *et al.*, 1984; Malme *et al.*, 1988, Würsig *et al.*, 1999). Oil and gas development operations can create high levels of underwater noise, especially operations associated with exploration and site establishment (Richardson *et al.*, 1995).

Industrial activities on the continental shelf off northeastern Sakhalin Island have steadily increased in the past five years and are scheduled to expand at a rapid pace. The nearly constant development and production activities during ice-free periods, in addition to the associated seismic surveying and increase in aircraft and shipping traffic now occurring near the western gray whale feeding ground, have introduced new sources of potential disturbance to the population. During summer 2001, 3D seismic surveys were conducted during a six-week period in known gray whale foraging areas off Sakhalin Island. The present paper provides results from an analysis examining the influence of seismic surveying during 2001 on the distribution of western gray whales while on their summer feeding ground.

METHODS

The study area was located off Piltun Lagoon (Zaliv Pil'tun) on the northeastern shore of Sakhalin Island, Russia (Fig. 1). A 35m lighthouse near the only channel connecting the inner lagoon with the Okhotsk Sea served as the base from which studies reported here were conducted.

Systematic one-hour scans, to determine the number of whales and pods within the study area, were conducted between 8 July and 26 September 2001. The scan area consisted of a 20 km long (north to south) and 5-km wide (east to west) area off the southern portion of Piltun Lagoon where whales are known to occur regularly and in appreciable numbers. Ten kilometers of the scan area was north of the lighthouse and 10 km to the south. All scans followed protocols used for similar studies conducted in the study area between 1995 and 2000 (Tsidulko, 1998; Ivashchenko, 1999; Blokhin *et al.*, 2001). Data included here were collected when Beaufort sea state conditions were ≤ 3 and visibility allowed the entire scan area to be viewed. Hand-held binoculars (7x50) were used to sight whales.

Seismic surveys in the area started on 1 August and ended on 8 September 2001. All seismic surveying occurred north of the lighthouse observation platform, in a region of the Sakhalin I project called the "Odoptu Block". The southern most portion of the Odoptu Block was located approximately 11 km north of the lighthouse, and therefore 1 km north of the northern most border of the scan area. Seismic vessels were commonly in view during the scans reported here. Three pre-defined conditions were examined in the following analysis: 1) Pre-Seismic (8 July - 31 July) - the period prior to the onset of seismic activity; 2) Seismic (1 August - 8 September) - the period when seismic surveying was conducted; and Post-Seismic (9 September - 26 September) - the period following termination of seismic surveys. Acoustic information, airgun specifications, and duty schedule are considered confidential to the company conducting the work and are therefore not available for inclusion in the following analysis.

RESULTS

A total of 55 shore-based scans were conducted on 35 days between 8 July and 26 September. Whales were present throughout the study period, but were especially high in numbers during the period when seismic surveying was being conducted to the north (Fig. 2). During the 55 scans, 515 groups consisting of 719 whales were sighted. The number of whales and number of pods detected per scan ranged from 1-32 and 1-25, respectively.

To test the hypothesis that the distribution of gray whales on the feeding ground would shift away (i.e. to the south) from nearby seismic surveying, we examined the number of whales and number of pods (dependent variables) sighted per scan in relation to three independent variables or "conditions" (i.e. pre-seismic, seismic, post-seismic) by analysis of variance (ANOVA). Both the number of whales and the number of pods varied by condition (Fig. 3). Results for the analysis of whales per scan showed the main effect of condition was significant ($F(2,52) = 21.5$, $p < .001$). Tukey's follow up comparisons revealed significant ($p = < .001$) differences in the mean number of whales sighted per scan between the pre-seismic (mean = 7.7; range = 3-14) and seismic condition (mean = 18.0; range = 6-32) and between the seismic and post-seismic (mean = 9.1; range = 1-15) conditions. Pre-seismic and post-seismic conditions did not differ from each other ($p = .778$). Descriptive statistics for this analysis are presented in Table 1.

Table 1. Descriptive statistics for mean number of whales and pods per scan.

Mean	Pre-Seismic (N = 15)	Seismic (N = 27)	Post-Seismic (N = 13)	F	P
Whales per Scan	7.7 (± s.d. 3.50)	18.0 (± s.d. 6.7)	9.1 (± s.d. 4.50)	21.5	< .001
Pods per Scan	6.1 (± s.d. 2.77)	12.4 (± s.d. 5.24)	6.8 (± s.d. 3.39)	13.1	< .001

The analysis of number of pods per scan revealed similar results. The main effect of condition was significant ($F(2,52) = 13.1$, $p < .001$). Tukey's follow up comparisons revealed significant (p = < .001) differences in the mean number of pods sighted per scan between the pre-seismic (mean = 6.1; range = 2-11) and seismic conditions (mean = 12.4; range = 5-25) and between seismic and post-seismic (mean = 6.8; range = 1-12) conditions. Pre-seismic and post-seismic conditions did not differ from each other (p = .900). Descriptive statistics for this analysis are presented in Table 1.

DISCUSSION

These findings indicate that significantly more whales and more pods were in the scan area during the seismic condition than during the pre- and post-seismic periods. These results suggest that whales shifted their distribution into the scan area (i.e. from the north to the south) and away from the northern region where seismic surveys were conducted between 1 August and 8 September. Once the seismic surveys had ceased on 9 September, overall whale and pod numbers in the scan area returned to pre-seismic levels, suggesting that whales had reoccupied the region from which they had been displaced.

Earlier studies (1997-2000) in the same study area (see Tsidulko, 1998; Ivashchenko, 1999; Blokhin *et al.*, 2001) have documented qualitative inter-annual variation in the timing of peak numbers of whales and pods off this portion of the feeding ground. However, these studies had differing degrees of offshore oil development activities occurring intra- and inter-annually that have yet to be quantitatively examined. The observed relationship between changes in whale distribution and seismic survey operations during 2001 so closely correspond (see Fig. 2) that the impact of such seismic activities cannot be discounted and must be viewed with serious concern. This is especially true when considering the ramifications of such activities on a critically endangered population, such as the western gray whale.

Several studies have demonstrated that eastern gray whales are sensitive to seismic survey operations, and therefore support the concern expressed here. Malme *et al.* (1988) specifically examined the influence of airgun pulses used during geophysical seismic exploration on gray whales while migrating and feeding. Results from this study suggested that whales had a high probability of being influenced by seismic-related noise, and had a 50% probability of avoidance behavior when exposed to sound levels of 170db when migrating and 173db when feeding (Malme *et al.*, 1988).

Similarly, playback experiments were conducted in 1984 in San Ignacio Lagoon, an important gray whale wintering area off Baja California (Dahlheim, 1987). In this time, oil-drilling recordings and other man-made sounds were broadcast in the lagoon during a total of 120 hrs, in 6 to 8 hour blocks, over the period of one month. Prior to the onset of the month long playback experiments, 123 single whales and 46 mother-calf pairs were present in the lagoon. At the completion of the study, the number of whales in the lagoon had decreased to 19 single whales and 24 mother-calf pairs. The 48% decline in the number of mother-calf pairs in the lagoon was thought to be the direct result of the playback experiments (Jones *et al*., 1986). A follow up study was conducted in 1985 to determine the overall abundance of gray whales in the same lagoon after the decline observed 1984 (Jones *et al.*, 1986). The highest number of mother-calf pairs counted in 1985 was 146 and the highest total whale count was 159. Jones *et al.* (1986) concluded that whales returned to and used this lagoon in 1985 as they had in previous years. This study provides an illustrative example of the temporary displacement (and subsequent reoccupation) of gray whales from critical habitat in response to industrial noise.

In addition to the reported displacement of gray whales from San Ignacio Lagoon in 1984, Dahlheim (1987) noted significant changes in gray whale calling rates and call structure during playback broadcasts and suggested that such responses could be detrimental for acoustically dependent whales. Although no data were collected on the acoustic behavior of western gray whales during the seismic surveys reported here, the results of Dahlheim (1987) suggest that this aspect of their behavior may have been impacted. This is of particular concern for mother-calf pairs that remain closely affiliated on the feeding ground until weaning occurs. Any reduction in acoustic contact between mothers and calves as a result of noise from nearby seismic surveying during this critical period of calf development may negatively impact their general fitness, ability to forage independently, and ultimate survival.

A previous study examining the influence of seismic surveys on western gray whales off the Sakhalin Island feeding ground was conducted by our research team in 1997 (Würsig *et al.*, 1999). During this time, acoustic recordings collected in nearshore gray whale foraging locations documented sound levels from seismic pulses of approximately 153 dB re 1 μPa, zero-to-peak; 159 dB re 1 μPa, peak-to-peak; and 139 dB re 1 μPa, averaged over one second while the survey vessel was 30-35 km from shore. These recordings indicated that even at relatively large distances, seismic noise was detectable within the primary feeding area. Behavioral reactions included changes in whale swim speeds and orientations, respiration patterns, and distribution offshore. These behavioral changes were hypothesized to be indicative of short-term disturbance to feeding behavior (Würsig *et al.*, 1999). The cumulative effects of such short-term disturbance, at both the individual and population level, are poorly understood, but in the case of critically endangered western gray whales, which depend on this area for seasonal fattening, minimizing such impacts is important to their well being and overall survival.

If the pre- and post-seismic conditions reported here are thought to reflect baseline distribution patterns for whales during 2001, the significant increase in whale numbers in the study area during seismic surveys and decrease in numbers after such surveys ceased suggest that the whales had been temporarily displaced from other areas (i.e. from the north to the south). Therefore, seismic survey activities probably limited access to the north-central portion of the feeding ground for most whales and prevented individuals from using areas where they were feeding prior to the onset of the surveys. The impact of limiting access to important feeding areas is of particular concern for whales identified to be skinny between 1999 and 2001 (see Brownell and Weller, 2001). Whales observed to be skinny in 2001 were in poor physical condition and required the maximum number of days feeding in high quality habitat to help recover. Similarly, whales observed to be skinny in past years (i.e. 1999 and 2000) also require optimal foraging to prevent complications of further malnourishment.

In 2001, six mother-calf pairs were identified off the Sakhalin Island study area (Weller *et al.*, 2002b). If these reproductive females were limited in their access to important feeding areas due to seismic operations, future calf production may be impacted. Perryman *et al.* (2002) suggest that access to feeding habitat is closely linked to calf production in the eastern gray whale population. Fluctuations in calf production of the eastern population between 1994-2000 were positively correlated with the length of time that primary feeding habitat was free of seasonal ice during the previous year (Perryman *et al*. 2002).

Further, half of the 14 known reproductive females in the population were observed to be skinny at some time during the past three summers (1999-2001), suggesting that their nutritional condition was compromised (Brownell and Weller, 2002). The elevated energetic demands of these reproductive females, especially those observed to be skinny, requires that they feed in high quality habitat for the maximum number of days possible within a season. Therefore, if these whales were feeding in suboptimal habitat as a result of seismic-related displacement, their future reproductive capabilities and survival may be affected.

Because gray whales aggregate off Piltun during summer-autumn to feed, we assume that their near shore distribution mirrors the distribution of their preferred prey. Therefore, displacement of whales by seismic survey operations may force them to forage in suboptimal locations and thereby potentially compromise their nutrition, health, and in the case of adult females, their reproductive capacity. Observations from aerial surveys in 2001 suggest that whales may have indeed shifted to secondary foraging habitat. In mid September 2001, various sources reported that whales were feeding offshore and well to the southeast of their typical distribution. No whales had been observed in that area during aerial surveys in the 1970s and 1980s (Berzin *et al.*, 1988, 1990, 1991) or in 1999 and 2000 (Sobolevsky, 2000, 2001). However, eight gray whales were sighted in that region during 2000 from a Japanese research vessel (Miyashita *et al*., 2001; Weller *et al*., 2002c).

The continental shelf off northeastern Sakhalin Island coast consists of two benthic communities, one inshore and one offshore (Koblikov, 1982). Both communities contain prey items consumed by eastern gray whales (Nerini, 1984), but based on analysis of fecal samples collected from western gray whales foraging inshore between 1998 and 1999, the primary prey for these animals are brackish-water amphipods (*Pontoporeia*) that occur almost exclusively near shore (Weller *et al*., in prep). Therefore, the unusual offshore and southern distribution of some whales recorded in 2001 may further reflect an overall displacement away from, or represent a within season abandonment of, the primary feeding area.

In the Beaufort Sea, the concerns of oil development activities (e.g. seismic surveys) on migrating whales (i.e. bowhead and gray whales) is related to the worst case being a temporary modification in behavior. That change is commonly characterized by a deflection (change in swimming direction) of their path while traveling in order to avoid the noise source. This type of behavioral modification is assumed to have a negligible impact on overall survival of individuals and therefore the population. The situation off Sakhalin Island is quite different from the above, however, as whales are for the most part resident to the feeding ground for 4-5 months and are therefore not merely migrating by sources of disturbance. In the case reported here, whales were not deflected, but instead displaced, during a critical period (i.e. feeding) of their life cycle. Both short-term and long-term cumulative effects of such disturbance may have impacts at both the individual and population level.

CONCLUSION

Although the relationship between the seismic survey operation period and the observed change in distribution of whales is only a correlation at this time, we strongly believe that it warrants an appropriate management response, i.e. seismic surveys should not be conducted while the whales are on their feeding ground. The western gray whale population is critically endangered and depends on the northeastern Sakhalin Island feeding ground for the majority of its annual food intake. Disruption of feeding in preferred areas is a biologically significant event that could have major negative effects on individual whales, their reproductive success, and thus, the population as a whole.

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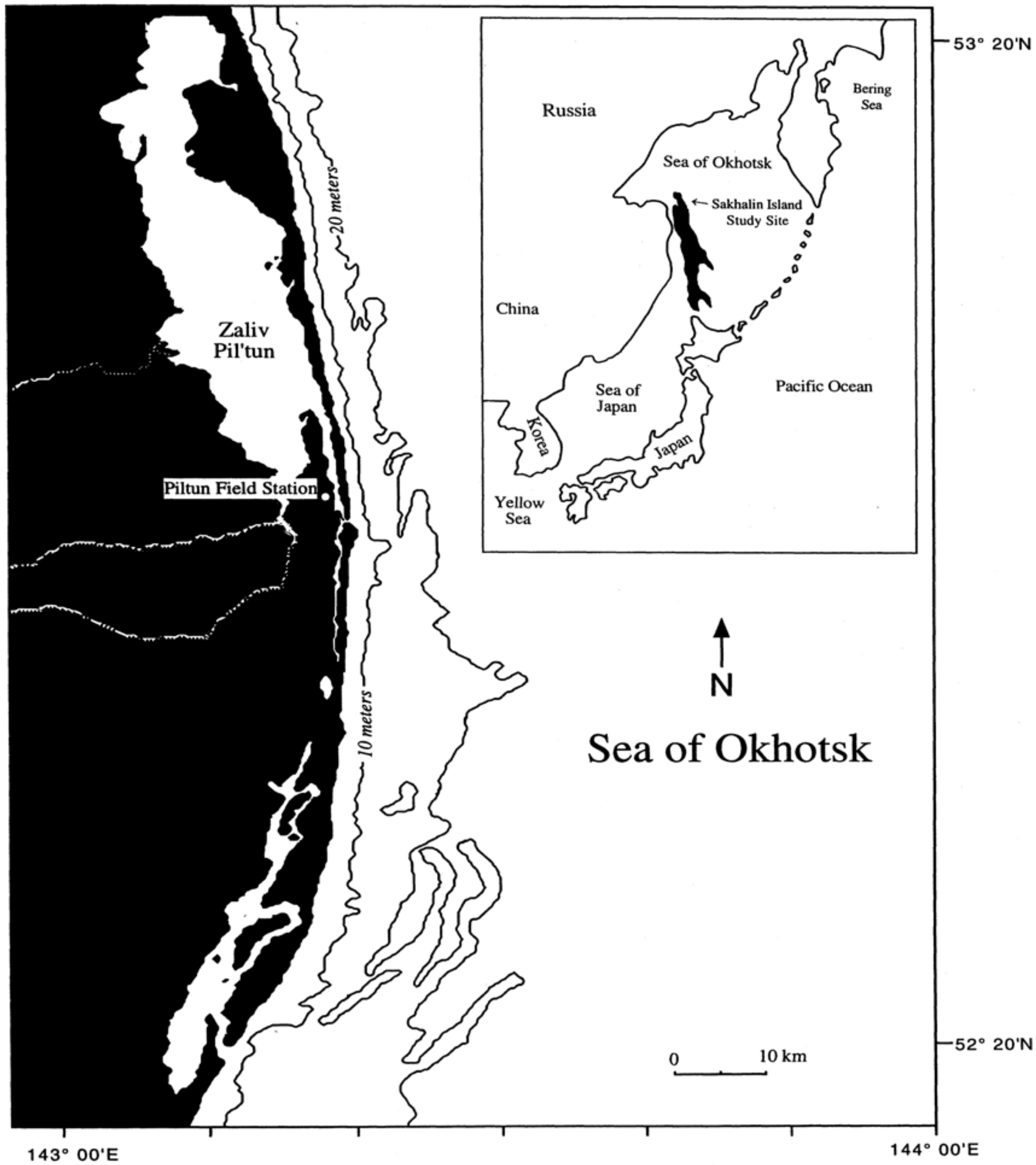

Figure 1. Study area located off Piltun Lagoon on the northeastern shore of Sakhalin Island, Russia.

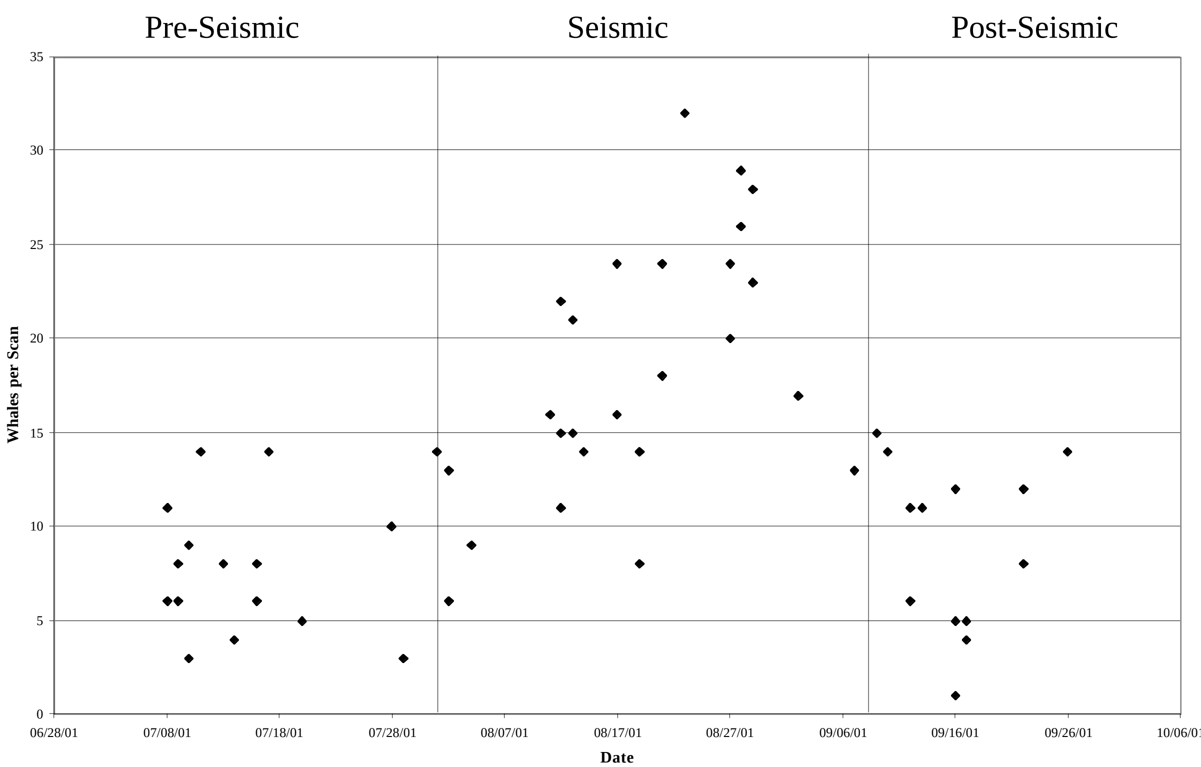

Figure 2. Number of whales counted per scan during pre-seismic, seismic, and post-seismic conditions.

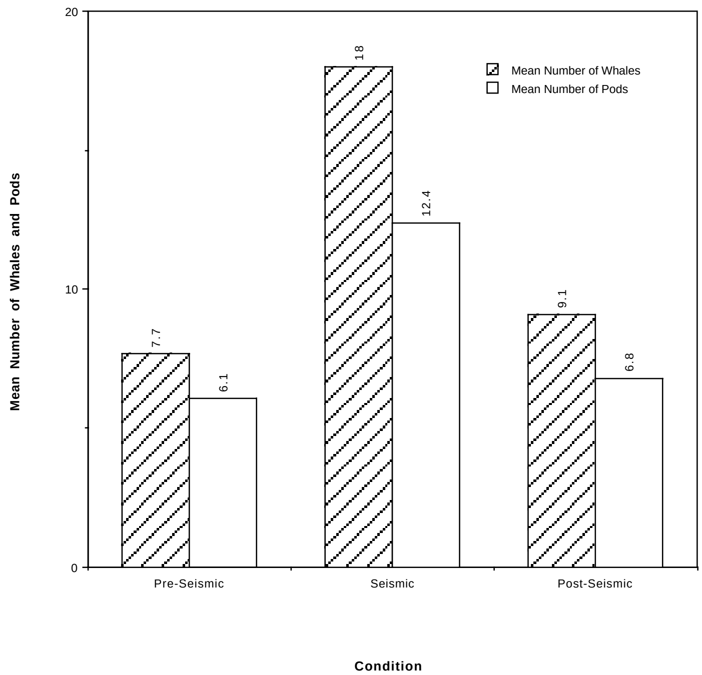

Figure 3. Mean number of whales and pods recorded during pre-seismic, seismic, and post-seismic conditions. Value labels represent means.