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Harbour Porpoise (*Phocoena phocoena*) Presence Patterns at an Aquaculture Cage Site in the Bay of Fundy, Canada

Marthe L. Haarr,[1] Laura D. Charlton,[1] John M. Terhune,[1] and Edward A. Trippel[2]

[1]*Department of Biology, University of New Brunswick, Saint John, New Brunswick, Canada E2L 4L5*
[2]*Fisheries and Oceans Canada, Biological Station, St. Andrews, New Brunswick, Canada E5B 2L9;*
E-mail: terhune@unbsj.ca

Abstract

Finfish aquaculture is a prominent industry in the Bay of Fundy, Canada. The distribution of harbour porpoise (*Phocoena phocoena*) in the Bay during the summer and fall may be impacted by the presence of offshore cages or the activities of workers on the site. Harbour porpoise presence near and within an aquaculture cage site was studied using visual observations during the summer of 2006 and by monitoring echolocation signals using T-PODs during the summer and autumn of 2006 and 2007. At least one harbour porpoise was sighted per hour 61% of the time among or near the cages. Porpoise occasionally surfaced within the cage site when workers were present. Mother-calf pairs used the within-cages area proportionately more than adults and juveniles. The porpoise were temporarily displaced by high disturbance activities such as cage cleaning with pressure hoses, but quickly returned to the area when the disturbance ended. Echolocation activity was lowest during the day, increased in the evening, and peaked between midnight and dawn. This pattern was evident on the offshore and inshore side of the cages and, to a lesser extent, at a non-aquaculture location farther along the coastline (2007 only). In August of both years, the echolocation patterns were similar, even though in 2007 there were no fish in the cages and much less worker activity than in 2006 when all 15 cages contained Atlantic salmon (*Salmo salar*). Echolocation activity near a T-POD typically lasted for no more than 10 min or for at least 1 h, suggesting that the porpoise were either passing by the area or staying to feed, respectively. The presence of the aquaculture cage site under study did not appear to be displacing harbour porpoise from the area except during short intervals when high disturbance activities such as a food delivery by barge or cage cleaning were occurring.

Key Words: T-POD, aquaculture, behaviour, echolocation, disturbance, displacement, harbour porpoise, *Phocoena phocoena*

Introduction

Harbour porpoise (*Phocoena phocoena*) enter the Bay of Fundy in early summer. Individuals often inhabit a localized area while foraging on small fish, and in the autumn, with a decline in food resources and water temperature, return to the Gulf of Maine (Gaskin, 1992; Trippel et al., 1999). There are numerous threats facing harbour porpoise across its range, including bycatch in gillnet fisheries and activities related to finfish aquaculture (Kraus et al., 1997; Trippel et al., 1999; Parsons et al., 2000). The aquaculture industry in the Bay of Fundy began in the 1980s (Trippel, 1999) and has grown to 96 aquaculture sites (Hellou et al., 2005), with the majority of these sites (95%) having Atlantic salmon (*Salmo salar*) grow-out cages.

Previous research has demonstrated that some marine mammals are attracted to aquaculture cage sites. Various pinnipeds such as harbour seals (*Phoca vitulina*), grey seals (*Halichoerus grypus*), Mediterranean monk seals (*Monachus monachus*), and California sea lions (*Zalophus californianus*) are common predators on marine fish farms (Nash et al., 2000; Güçlüsoy & Savas, 2003; Quick et al., 2004; Nelson et al., 2006). Such a relationship has not been documented explicitly for harbour porpoise, but they have been observed feeding on fish from trawls (Fertl & Leatherwood, 1997). Bottlenose dolphins (*Tursiops truncatus*) are also known to feed near aquaculture cage sites (Díaz López, 2006) where they exploit aggregations of small fish that are attracted to the excess feed from the cage site (Boyra et al., 2004; Díaz López, 2006). Similarly, harbour porpoise, in turn, may be attracted to aquaculture cage sites for their rich forage fish base. Prey fish such as herring (*Clupea harengus*) and mackerel (*Scomber scombrus*) may be attracted to aquaculture cage sites in search of particulate farm food (Black et al., 1992). At times, a cage site also may act as a breakwater and provide some degree of protection from harsh weather conditions.

Harbour porpoise are often reported as being exceedingly "shy" animals, wary of boats and other human activity (Barnes, 1999). Potential disturbance of harbour porpoise by aquaculture sites may result from worker and boat activity. Acoustic harassment devices (AHDs) have been used on some fish farms to purposely displace marine mammals (Olesiuk et al., 2002). The potential magnitude of these disturbances on harbour porpoise remains unclear.

One method of studying the presence of harbour porpoise is acoustic monitoring of echolocation activity (Carstensen et al., 2006; Koschinski et al., 2006). A porpoise echolocation click passive acoustic monitoring system, T-POD, records the time when echolocation clicks occur (Verfuß et al., 2007), thereby providing a method to acoustically monitor the presence of harbour porpoise (Carstensen et al., 2006)

The objectives of this study were to investigate the patterns of harbour porpoise presence at an aquaculture cage site. The factors examined included (1) determining if harbour porpoise will enter a cage site while workers are present, (2) assessing possible long-term displacement associated with anthropogenic disturbances, (3) assessing the times of day when harbour porpoise are near or within the cage site, and (4) determining if porpoise are only traversing through the cage site area or if they are staying for longer periods.

Materials and Methods

Location

The main study site was a group of aquaculture cages located at Crow Island near Back Bay, New Brunswick, Canada (45° 02' N, 66° 52' W; Figure 1). The site had 15 Atlantic salmon cages (30-m diameter polar circles). It was also an integrated multitrophic aquaculture (IMTA) trial site for combining mussel (*Mytilus edulis*) socks and kelp (*Saccharina latissima* and *Alaria esculenta*) rafts with the salmon culture. A stationary barge used for supplying fish feed to the cages was located in front of the center row of the cages on the inshore side of the site. In the second year of the study, a non-aquaculture reference site was established close to shore, 0.9 km farther into the bay.

Visual Observations 2006

Visual observations were made Monday, Wednesday, and Friday from 16 June to 23 August 2006 either in the afternoon from 1300 to 1900 h or in the morning from 0900 to 1500 h. Observations were made on 7, 13, and 9 days in June, July, and August, respectively. Two observers from shore scanned the entire aquaculture site once every 10 min (binoculars, 35 × 50) for a total of 5 min. Scans with the naked eye would take place during the intervening period. When a porpoise was observed, the time of sighting and the approximate location were recorded. The site was classified into one of four areas: (1) the inshore area between the shoreline and cages, (2) among the cages, (3) a band approximately 30 to 60 m around the outside of the cages, and (4) the offshore area beyond 60 m from the cages (Figure 1). The number and sizes (juvenile/adult or calf) of harbour porpoise were estimated in each group. Calves were noticeably smaller than juvenile or adult porpoise. To avoid counting the same individual twice, a single porpoise would be followed until it disappeared from sight for more than 5 min. If another porpoise appeared after this time period (or in a different location), it was assumed to be a previously unsighted individual. No other species of odontocetes or pinnipeds were observed in the area.

A chi-square test was performed to determine if there was a significant difference in the preference of the four areas of the site between adult/juvenile porpoise and mother-calf pairs. The offshore area was assumed to take up 50% of the site (thus 50% of the sightings were expected to be there), Area 3, just outside the cages was 17%, and Area 2 within the cages was 33% (Figure 1). The inshore area was excluded from this test as there were too few sightings (only three porpoise were seen in this area over the summer).

The times during which a disturbance occurred near or within the site were noted. The disturbances were categorized into four types: (1) small boat traffic, (2) large moving barges (18 m × 9 m), (3) cage cleaning (involving the use of a high pressure hose), and (4) large moving barges and cage cleaning. The number of porpoise present at the immediate end of the disturbance and 5 and 10 min later were recorded. Linear regression analysis was performed to determine if porpoise presence was related to time after the end of a disturbance.

Acoustical Monitoring 2006

In 2006, a T-POD (Version 4, Chelonia Ltd., www.chelonia.co.uk) was deployed from 23 June to 10 July, 12 July to 4 August, 11 August to 1 September, 4 to 23 September, and 25 September to 23 October (Figure 1). During the first deployment, this T-POD was located near the offshore side of the cage site, along a food delivery line (Figure 1). For the remaining four deployments, it was located on the inshore side of the cages, next to the stationary feeding barge. This barge was approximately 360 m from land (45° 2.615' N,

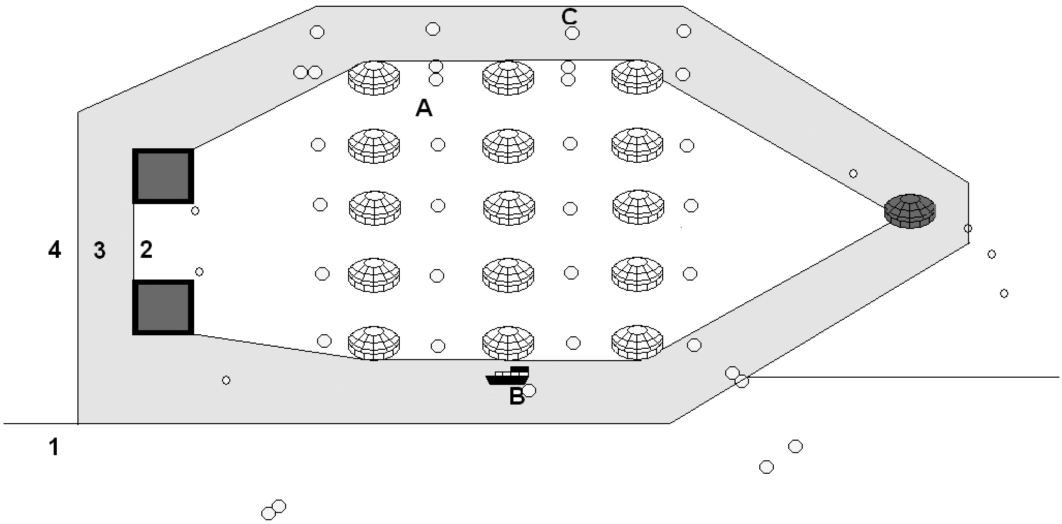

Figure 1. The Crow Island aquaculture site, divided into four sections: (1) inshore, (2) among the cages, (3) around the cage site, and (4) offshore; the lines represent boundaries between the four areas. The site consisted of three types of cages: (1) two kelp cages on the left (squares), (2) 15 salmon cages in the middle, and (3) a mussel cage on the right. The small circles denote the location of buoys. The T-PODs were located at (A) offshore 2006, (B) inshore 2006 and 2007, and (C) offshore 2007. The control site was located to the left of the kelp cages.

66° 52.407' W). The cages contained fish throughout the 2006 study period.

For the first three T-POD deployments in 2006, the times when the T-POD detected a porpoise were compared to the times when an observer sighted a porpoise. The points where a sighting occurred at the same time as click detections (1) and where a sighting was made but no clicks were detected (0) were plotted on a map of the site for each deployment.

Acoustical Monitoring 2007

In 2007, three T-PODs (one Version 4 and two Version 7) were deployed from 30 July to 23 August, 6 September to 4 October, and 14 October to 12 November. The cage site was fallow until 2 October when fish were added to one cage and to another eight cages from 2 to 14 October. One T-POD was deployed inshore of the cages near the stationary barge, one just offshore of the cages at a mooring buoy (45° 2.454' N, 66° 52.421' W), and the third further up the bay at a mooring buoy 210 m from shore (45° 2.943' N, 66° 51.977' W). This third T-POD was intended as a partial control because it was away from the human activity around the cage site and close to shore. The distances between the sites were calculated using the rhumb line calculator (www.columbus navigation.com/rhumb.shmtl). The distance from the inshore site to the offshore site was 0.30 km, the distance from the inshore site to the control site was 0.88 km, and the distance from the control to the offshore site was 1.12 km. The T-PODs were rotated after each deployment so that one T-POD was not in the same location twice to minimise any potential bias from differing sensitivities of the three T-PODs. There were no active AHDs in the area in either year.

Statistical Analysis – Acoustical Data

The data were downloaded from the T-PODs after each deployment and processed to identify the harbour porpoise echolocation trains (Carstensen et al., 2006; Leeney et al., 2007). The number of clicks detected every 10 min were used in subsequent analyses either as the actual count of clicks or as an index of clicks present or absent in each recorded 10-min period.

The data were first analysed using basic descriptive statistics depicting the average echolocation activity every hour over a 24-h period for each deployment at each of the three study sites. This was done using the proportion of 10-min periods each hour with positive detections.

Cyclical activity patterns were analysed using Fourier decomposition spectrum analysis (*Statistica 8.0*, StatSoft Inc.). The Fourier analysis was carried out for each location and deployment, using the total recorded clicks every 10 min over consecutive 24-h periods.

An index of how long porpoise remained in the area once they were present was obtained using the 2007 acoustical data. The number of clicks in the first 10-min period that followed a 10-min period without any clicks was categorised into > 0, > 100, > 500, and > 1,000 clicks. The number of consecutive 10-min periods that followed and contained clicks was noted.

Results

Visual Observations 2006

Despite occasional poor visibility due to waves, rain, and/or fog, at least one porpoise was sighted per hour 61% of the time. Overall, there were 5.6, 14.5, and 18.1 groups per 6-h d sighted in June, July, and August, respectively. Adult-juvenile sightings were made from the first day of observations until the last. The first mother-calf sighting occurred on 26 June, with the last sighting made on the last day of observations. Adult-juvenile groups were sighted 342 times with group sizes ranging from one to six porpoise (mean ± SD = 1.6 ± 0.8). Forty-eight mother-calf groups were sighted with group sizes ranging from one (single calf) to four (two mother-calf pairs) (mean = 2.6 ± 0.9).

Most porpoise, particularly adults and juveniles, tended to move in a straight path in and out of the bay on the offshore side of the cages. Occasionally, an individual or a small group would be observed swimming in a concentrated area (possible feeding behaviour). Mothers and calves tended to swim in concentrated areas more than adults and juveniles.

The chi-square test indicated that there was a distinct difference in the areas by adult-juvenile and mother-calf groups. Adult-juvenile groups were sighted more often in the offshore area of the site (Figure 1, section 4; $n = 166$) as opposed to around the cage site (Figure 1, section 3; $n = 108$) or among the cages (Figure 1, section 2; $n = 66$) ($\chi^2 = 62.71$, df = 2, $p < 0.001$). Mother-calf groups were sighted more often among the cages (Figure 1, section 2) and around the cage site (Figure 1, section 3; $n = 16$ and $n = 18$, respectively) compared to the offshore area (Figure 1, section 4; $n = 13$; $\chi^2 = 17.25$, df = 2, $p < 0.001$).

Porpoise were observed among the cages when workers were present. For each of the four disturbance categories, on at least one occasion, a porpoise was sighted within 1 min after the disturbance ended. There were no significant differences (Table 1) between the number of porpoise present at the end of each of the four disturbance types ($F_{(3, 279)} = 0.951$, $p = 0.416$), or after 5 min ($F_{(3, 279)} = 1.522$, $p = 0.21$) and 10 min ($F_{(3, 279)} = 0.308$, $p = 0.82$). A linear regression analysis showed no significant relationship between the number of porpoise present and the time that had passed since a large disturbance ($r^2 = 0.007$, $t = 0.52$, df = 1, $p = 0.61$).

Acoustical Monitoring 2006

For the first T-POD deployment, near the offshore side of the cage site, echolocation clicks were detected at the same time a porpoise was sighted for approximately 58% of the total observations. Deployment two at the onshore side of the cage site had the greatest number of sightings, and the times of clicks detected by the T-POD corresponded to 23% of the visual observations (Figure 2). Deployment three had only 15% of visual sightings occurring at the same time as T-POD detections. Overall, porpoise sightings at the same time clicks were detected occurred only 27% of the time. Also, 95% of the porpoise sightings that coincided with echolocation clicks were greater than approximately 50 m from the T-POD.

The proportion of 10-min periods/h with positive click detections showed a similar daily pattern. A general pattern of higher echolocation activity between midnight and 0600-0700 h and low activity during the day 0700-0800 h to 1800-1900 h occurred at both the offshore and inshore locations (Figure 4). The T-POD data were analysed in 10-min segments of which there are 144 in 24 h. For every deployment at each of the locations in both 2006 and 2007, the Fourier analysis indicated a distinct peak in the periodogram at 144 cases, thus indicating a 24-h cycle was consistently present. A tidal cycle of 12.4 or 24.8 h contains 75 and 149 10-min periods respectively. The Fourier analysis showed no peaks at 75 or 149 cases, indicating that echolocation activity was not correlated to a tidal cycle.

Acoustical Monitoring 2007

The 24-h cycle of echolocation activity pattern observed in 2006 was also evident in 2007 (Figure

Table 1. Number of harbour porpoise (mean ± SD) sighted at the end of disturbances at the aquaculture cage site as well as 5 and 10 min later; *n* = number of observations of each disturbance.

Disturbance type	At end of disturbance	5 min later	10 min later	*n*
Small boat	0.12 ± 0.51	0.60 ± 1.24	1.09 ± 1.88	175
Barge	0.00 ± 0.00	0.19 ± 0.40	0.69 ± 1.35	16
Cage cleaning	0.19 ± 0.73	0.80 ± 1.44	1.11 ± 1.75	70
Barge + cleaning	0.00 ± 0.00	0.95 ± 1.43	1.23 ± 1.77	22

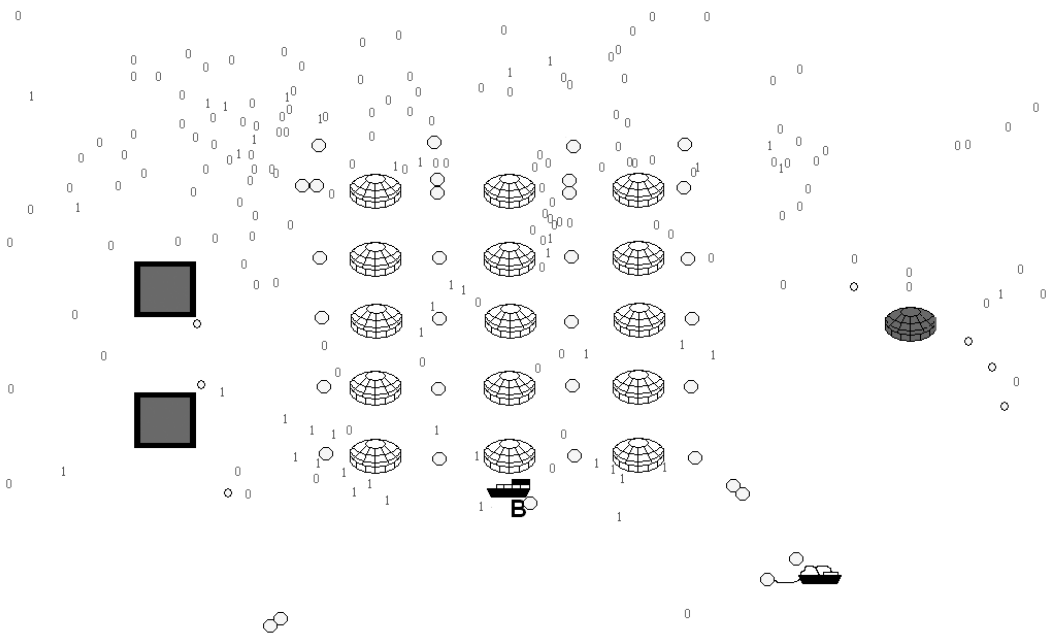

Figure 2. Location of the porpoise observed in July 2006; a code of "1" indicates echolocation clicks were detected by the T-POD at the same time this porpoise was observed, and "0" indicates no clicks were detected. The T-POD was located at "B."

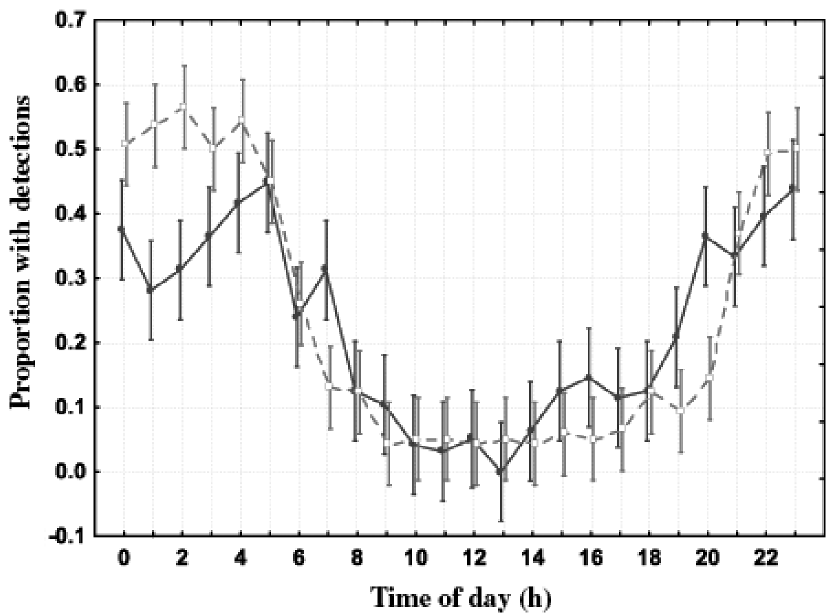

Figure 3. Diel changes in the mean proportion of 10-min periods/h with harbour porpoise echolocation signal detections from August 2006 (●) and 2007 (□) using 17 overlapping sampling days only; vertical bars denote 0.95 CI.

3; the same 17 d in August of both years were analyzed). This daily pattern was evident at all locations per T-POD deployment, although there were differences between them. There was greater overall activity at the offshore site than at the inshore and control sites (Figure 5).

The analysis of the number of consecutive 10-min periods within an hour in which porpoise

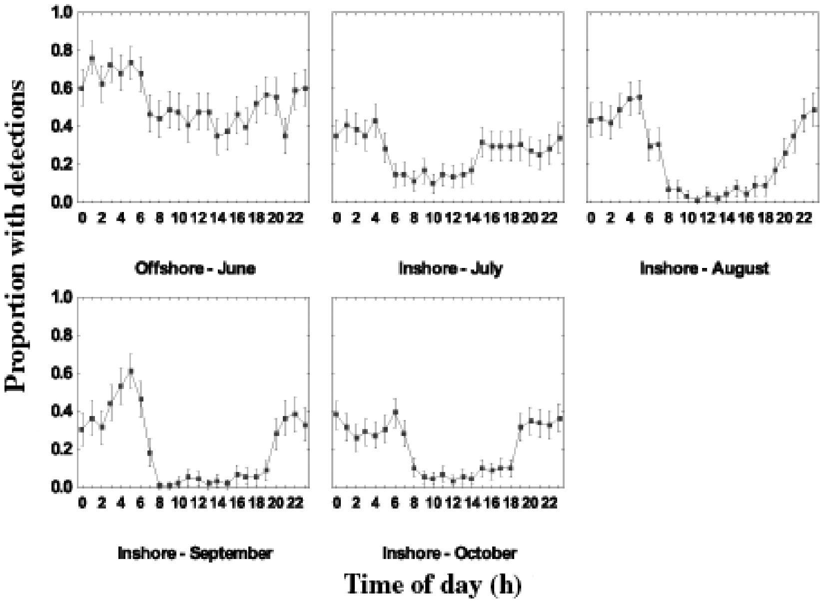

Figure 4. Diel changes in the mean proportion of 10-min periods/h with harbour porpoise echolocation signal detections for each location and deployment in 2006; error bars denote 0.95 CI.

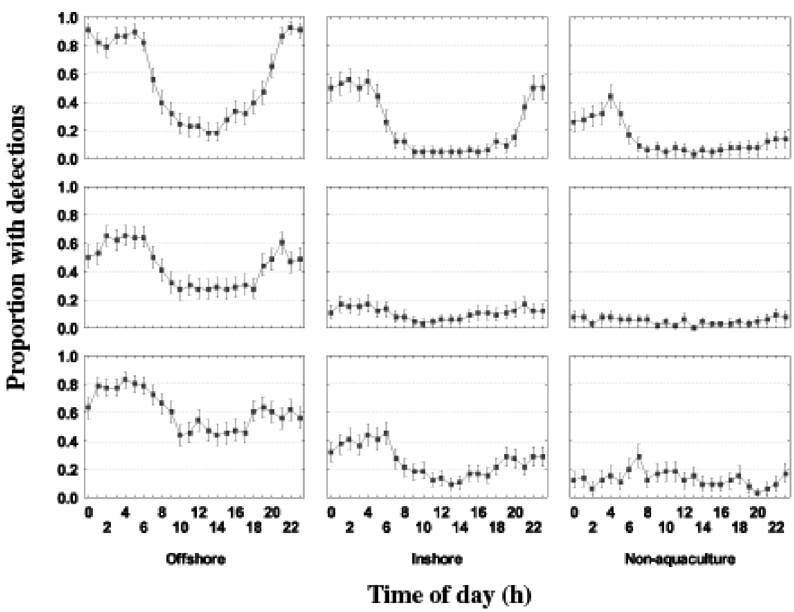

Figure 5. Diel changes in the mean proportion of 10-min periods/h with harbour porpoise echolocation signal detections for each location and deployment in 2007; error bars denote 0.95 CI.

echolocation clicks were detected showed a bimodal distribution of duration (Figure 6). These two modes were at one and six consecutive 10-min periods with positive detections. This bimodal pattern was also seen after an initial 10-min period with more than 100 clicks, although the pattern became unimodal when the initial 10-min periods contained more than 500 or 1,000 clicks, and the porpoise remained active nearby for a full hour afterwards for the majority of the time (Figure 6).

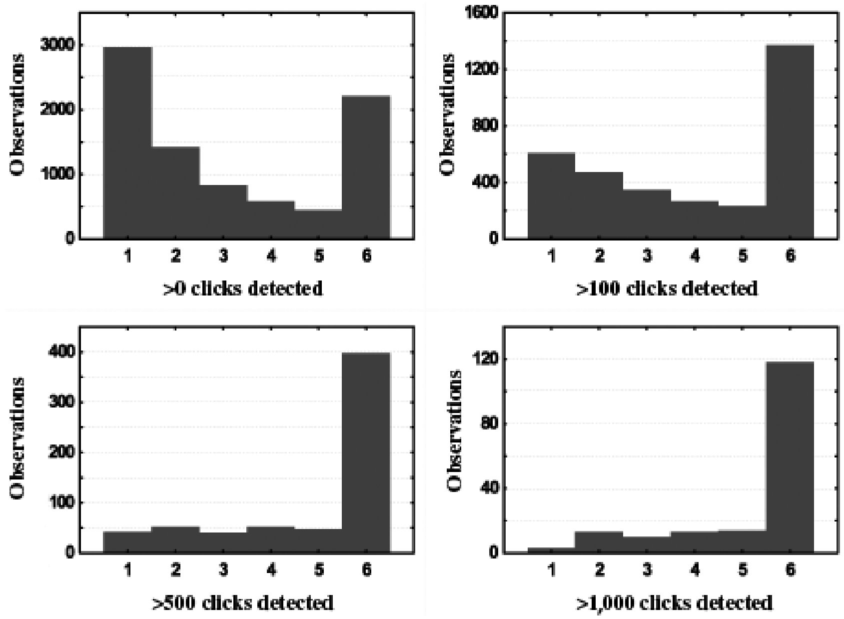

Figure 6. Histograms of the sums of consecutive 10-min periods with harbour porpoise echolocation clicks following an initial period with > 0, > 100, > 500, and > 1,000 clicks (2007 data)

Discussion

Not all porpoise in the study area would have been sighted. This is especially the case for animals on the offshore side of the cages and for the smaller calves. Calves were more difficult to detect than adults. Thus, some mother-calves could have been placed in the adult-juvenile group simply because a calf was not seen. Conversely, although few porpoise were sighted in the inshore area, because this was the area closest to the observers, it is unlikely that any porpoise surfacing there would have been missed.

The increase in observed porpoise numbers from June to August 2006, and the peak echolocation activity in August of both years followed by a decline in the fall, is consistent with the reported natural migration pattern of harbour porpoise in the Bay of Fundy (Gaskin, 1992; Trippel et al., 1999).

Both adult-juvenile porpoise and mother-calf pairs frequented areas within the cage site. Smith & Gaskin (1983) stated that females and their young tend to seek out more stable areas in their habitat. With the cages acting as a physical barrier against harsh weather conditions and possibly protection from natural predators, the mother-calf pairs may be using the site to their advantage instead of avoiding it. Also, the porpoise may have been feeding within the site. The relationship between high click rates and the longer periods of continuous presence in an area suggest feeding behaviour. Conversely, 10-min periods with low click rates were often followed by silent periods suggesting that the porpoise were travelling through the area.

Visual observations in 2006 suggest that porpoise are temporarily displaced by the different types of boat traffic and work around the cage site as fewer were seen during times of such disturbances. This is not unexpected as harbour porpoise have been reported as "shy" animals that tend to avoid motorized watercraft (COSEWIC, 2003; Olesiuk et al., 2002). However, they did return within a very short period of time once the disturbance ended. Thus, although it seems that the human activities around the site influenced porpoise movements, it was not long-term. This is consistent with the findings of Kastelein et al. (2000) wherein behaviour of harbour porpoise returned to normal within a minute of acoustical alarms being switched off.

If harbour porpoise were displaced by worker activity at the cage site, the pattern of porpoise activity would be expected to be lower during the day at the inshore site and higher at the non-aquaculture site. This was not the case as the 24-h cycle was the same for all three study sites, indicating that the greater echolocation activity during the night may be a natural pattern and not one related to human disturbances. This is consistent with the diel echolocation activity pattern reported of harbour porpoise around offshore gas platforms in the North Sea (Todd et al., 2009). Furthermore, if porpoise were displaced by worker activity, one would expect the pattern of activity during the daytime to be lower when there were fish in the cages compared to the summer when there were not. Worker activity was substantially less in 2007 prior to fish being added to the cages, and there were few major disturbances such as cage cleaning and feed delivery. The same porpoise echolocation activity pattern was observed in both years, however. This suggests that the reason for low echolocation activity during the daytime is not directly related to porpoise avoidance of the area because of human disturbance.

The high levels of echolocation activity at night in August 2007 when no fish were in the cages suggests that the porpoise were not necessarily attracted to the cage site to feed on small fish outside the cages. The higher echolocation activity at night may reflect the tendency to come closer to shore at night, or simply the greater use of echolocation in darkness (Carlström, 2005). The greater echolocation activity and number of observed porpoise in the offshore area compared to the two inshore areas is likely due to the offshore area being close to both the centre and mouth of the bay and, thus, including porpoise entering or departing the bay. The inshore and non-aquaculture sites were much closer to shore and, thus, in shallower water. Smith & Gaskin (1983) found the presence of harbour porpoise mother-calf pairs to be positively correlated with increasing bottom depth during the day.

The T-POD cannot distinguish between individual harbour porpoise, nor can it detect a porpoise unless it is echolocating. This means that the data collected by the T-PODs is an index of overall echolocation activity, which may not be an accurate depiction of overall porpoise presence. This is supported by the pairing of acoustical and observational data from 2006 when only 27% of the time were echolocation clicks recorded at the same time as porpoise were observed. This rate is similar to that reported by Koschinski et al. (2006) for occasions when harbour porpoise were within 50 m of a T-POD. It is, therefore, highly likely that there were periods of harbour porpoise presence that went undetected by the T-PODs (Philpott et al., 2007). Also, 95% of the porpoise sightings that coincided with echolocation clicks were greater than approximately 50 m from the T-POD and some were so far away that they were unlikely to have been the animal detected by the T-POD (Figure 2).

Further visual observations would need to be conducted during both the day and night and compared to simultaneous T-POD recordings in order to investigate whether the pattern of lower echolocation activity during the day is the result of porpoise being present less often or simply due to them echolocating less frequently during the day vs night. The apparent weakening of the pattern later in the fall may be due to fewer porpoise being present in November than in August.

These findings suggest that the presence of an aquaculture cage site is not influencing harbour porpoise distribution other than at times when a temporary disturbance is occurring. The presence of harbour porpoise when there were no fish in the cages could be attributed to their simply coming closer to shore at night or echolocating more, independent of the presence of a cage site. The sampling at only a single cage site and the limited data gathering restrict extrapolation of our observations to other locations. Our findings, however, support the hypothesis that the presence of finfish aquaculture cage sites, without active acoustic harassment devices, does not result in long-term displacement of harbour porpoise from their natural habitat.

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