Abundance and Distribution of Harbor Porpoises and Other Cetaceans

in the San Juan Channel:

Tides and Bathymetry

Kia R. R. Hayes

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Friday Harbor Laboratories, University of Washington

Contact information:

kiarosehayes@gmail.com

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Abstract:

The Salish Sea, an area of complex oceanography and bathymetry, supports a number of apex cetacean species. In the last decade, anomalous sightings of cetaceans have become more frequent and shifts in species abundance have occurred. This 2014 Pelagic Ecosystem Function (PEF) study, using large and fine scale surveys in the San Juan Channel (SJC), determined that cetacean mean density was unusually low but species composition was more diverse than previous years, perhaps due to anonymously warm surface water. The relationship between tides, bathymetry and harbor porpoise abundance at small scales were different than those found previously in the region.

<u>Introduction:</u>

The San Juan Archipelago (SJA), located in the Salish Sea, supports a number of iconic cetacean species that are both economically and ecologically important to the area. Most of the cetacean species are only present in the area during summer and migrate south for winter. The fall and winter resident cetacean fauna have historically been less diverse, comprising mostly harbor porpoise (*Phocoena phocoena)* and Dall's porpoise (*Phocoenoides dalli*). In the last decade, anomalous sightings of cetaceans have become more frequent (Calambokidis 2014). The reasons for this change in community composition are unclear but the developing trends are intriguing. The further monitoring of local indicator species/top predators could serve to have great implications for understanding the health of the Salish Sea ecosystem.

Among the most dramatic changes of cetacean populations have been those described for the harbor porpoise. The harbor porpoise is a year-round resident and smallest cetacean in the Salish Sea. After decades of decline and verging on local extinction, harbor porpoise populations have steady increased over the last decade (Calambokidis 2011). Although harbor porpoise populations in the San Juan Channel (SJC) have received relatively little recent attention during the fall season, data from previous PEF research in the SJC also shows a steady increase in harbor porpoises since the early 2000's (Vermeire 2010, Wilkins 2011, Teller 2012). As a top predator, harbor porpoises have the potential to greatly influence the ecology of an area (Williams et. al 2004). Harbor porpoises are also particularly vulnerable to human activities and environmental change and are considered to be an indicator species of ecosystem health. (Baird 2003).

Marine mammals such as the harbor porpoise that inhabit estuaries are not only limited to foraging and living in certain areas but they also are constrained to certain tidal conditions in which their prey is abundant (Johnston et al. 2005, Stevick et al. 2008, Scott et al 2010). The tidal coupling hypothesis described by Zamon (2003) explains that tidal rips and jets influence zooplankton distribution and abundance and lead to short term increases in abundance of forage fish abundance. For this reason it is probable that tidal and other small scale variables affect harbor porpoise abundance. However, the relationship between harbor porpoise foraging sites and oceanography are not fully understood (Hooker et. al 2004).

Overall, my goal was to assess the status of cetaceans and especially harbor porpoises in the SJC fall 2014 and inter-annually. The large-scale objectives of this study were to determine cetacean abundance, distribution, and species composition this year and compare my findings to previous years. My second objective was to continue to examine the effects of tides and bathymetry on harbor porpoise abundance and distribution. Building on the work of Teller (2012) and Bliss (2013), I conducted fine scale surveys at short time and space scales and combined the three-year data set for analysis.

<u>Methods:</u>

San Juan Channel – large-scale surveys

Large-scale surveys were conducted from the *R/V Centennial* along a 21.11 km transect in the SJC in fall 2014. Surveys were conducted September 30; October 7, 14, 21 and 29; November 5 and 10. The transect was subdivided into six zones of different lengths (figure 1). Zones differ bathymetrically and oceanographically. The coordinates and areas of the six zones are as follow: Zone 1: 48°35'N, 122°59.75'W, area: 1.26 km^2; Zone 2: 48°33'N, 122°59.75'W, area: 0.96 km^2; Zone 3: 48°32'N, 122°58'W, area: 0.93 km^2; Zone 4: 48°31'N, 122°57'W, area: 1.68 km^2; Zone 5: 48°28'N, 122°57.2'W, area: 1.17 km^2; Zone 6: 48°26'N, 122°56.75"W, area: 0.45km^2. Densities of animals were calculated by the number of individuals/zone area.

Surveys were conducted using the strip transect method (figure 2). Observers (2-10 individuals) sitting on either side of the bow of the *R/V Centennial* recorded animals observed within a 200 meter bounded corridor and in one-minute intervals. Observations were done using binoculars and visual identifications. The *R/V Centennial* speed ranged between 5-12 knots and the entire transect was covered twice each day weekly.

For inter-annual comparisons, I used data collected by previous PEF research from 2007 onwards. The data collected in 2013 had not been analyzed and is presented as new findings along with my 2014 data. For quality assurance, I re-analyzed a few previous years data to confirm they were comparable to my methods.

Griffin Bay Transect – Fine Scale Surveys

Fine-scale surveys were conducted using the Friday Harbor Laboratories (FHL) *R/V Auklet*. Transects were conducted on October 22nd (3 transects); October 24th (4 transects); October 26th (2 transects); October 27th (5 transects); November 7th(8 transects). Some survey days had more or less transects due to weather and available light. The boat traveled between 5-8 kts while on transect. Surveys were conducted back-to-back and were approximately 30 minutes apart. The transect was 4km long ranging from the south end of Griffin Bay (48˚ 28,256'N, 122˚ 57,517'W) to the north end of Griffin Bay (48˚ 30,250'N, 122˚ 57,837'W)(figure 3). Surveys were conducted using an unbounded corridor observation method. Using this method, observers on either side of the boat recorded all animals seen in the area in one minute intervals. In comparison, a bounded observation method only records animals within a certain distance from the boat, as done during *R/V Centennial* surveys*.* Surveys were conducted during tides that had a maximum current speed between 2 and 3 kts. Surveys were only conducted in conditions when wind was less than a 2-3 force on the Beaufort Wind Scale. WWW Tide/Current Predictor, NOAA Tides and Mobile Geographics sites were used for current speed, tide, and weather predictions.

Tidal phase was categorized by timing and current speed with flooding phases being SF=.5 kts to 1.5 kts and FF= ≥1.5 kts; Ebbing phases being SE= -.5 kts to -1.5 kts and FE= ≥-1.5 kts, and slack being SL=-.5 to .5 kts. Tidal phases were also divided by first (1) and second (2) half of either flooding or ebbing tide.

The transect was designed in 2012 to run along an underwater cliff so each side of the boat represents different depths of water. Off the starboard side of the boat, the channel was approximately 170m deep. Off the port side of the boat the channel was approximately 85m deep (Figure 4). To study depth preference, if a porpoise was observed on the starboard side of the boat they were recorded as swimming/foraging in the deep portion of channel. If observed on the port side they are recorded as swimming/foraging in the shallow portion of the channel.

For inter-annual comparisons, I used data collected by previous PEF researchers in 2012 and 2013 (Teller 2012, Nordstrom 2012, Eisenlord 2012, Bliss 2013). The original 2012 data analysis used different methods for calculating current speed and tidal phases. To allow for inter-annual comparison, I have recalculated many of the averages, densities, and correlation between tidal speeds and phases from 2012. Another difference between data collected in 2012-2013 and 2014 is that past years used a strip transect method for observing, only recording porpoises observed inside a 200m corridor.

Results:

Large Scale:

Community composition –

During Fall 2014, we observed a total of six types of cetaceans on *R/V Centennial* transects. The observed cetaceans included the harbor porpoise, Dall's porpoise, killer whale, minke whale, Pacific white-sided dolphin (PWD), and humpback whale. This year was the first time killer whales, minke whales, and humpback whales were seen on transect in the last 8 years. PWD were the most abundant with 28 observed individuals and an average density of 0.35 individuals/km^2 , but were only observed during a single cruise. PWD have only been observed in 2013 and 2014 during PEF cruises in the SJC. The harbor porpoise had the second highest density with 26 observed individuals with an average density of 0.31 individuals/km^2, but were the most frequently observed cetaceans over the seven cruises. The remaining cetacean species observed had considerably lower densities (figure 5) and were only seen during one cruise each.

Harbor porpoise abundance –

In 2014 we observed a significantly lower density of harbor porpoises than observed in previous years (figure 6). A total of 26 harbor porpoises with an average density of 0.31 individuals/km^2 were observed from the *R/V Centennial* this Fall. In Fall 2013, a total of 133 porpoises were observed with an average density of 1.47 individuals/km^2. Inter-annual data shows that 2013 follows a trend of steady increase in porpoises since 2007 but in 2014 there was a sharp decline (figure 6).

Harbor porpoise abundance decreased throughout the season and were only observed during four of seven Fall *R/V Centennial cruises* (figure 7). This decline occurred mid October around the time of the fall transition. During the first cruise on September 30th, a total of 11 harbor porpoises were observed. During the last cruise on November 10th, 4 harbor porpoises were observed with a density of 0.62 individuals/km^2.

Harbor porpoise distribution in the San Juan Channel –

In Fall 2014, harbor porpoises abundance was highest in zones 2 and 3 with densities ranging from 1 to 11 porpoises/km^2 (figure 8). Harbor porpoises were also observed in zones 1,4, and 5, with densities below 3 individuals/km^2. The distribution pattern of 2014 differs from previous years where harbor porpoise densities were highest in zones 3 and 4 (figure 9).

The 2014 distribution pattern described above was not consistent for all cruises that observed harbor porpoises (figure 8). The first two trips on September 30th and October 7th followed the above pattern with highest densities of harbor porpoises found in zones 2 and 3. The fourth cruise on October 21st showed highest densities in zones 1 and 3. The last cruise on November 10th only observed harbor porpoises in zone 2.

Small Scale Surveys:

This year we observed a significant decline in harbor porpoise abundance during small boat transects in fall 2014. A total of 37 harbor porpoises were recorded, or 1.42 individuals/transects (figure 10). Density was not calculated due to lack of a bounded corridor. No porpoises were observed during the October 27th survey. In comparison, 2013 surveys recorded 178 harbor porpoises, or 4.8 individuals/transect. In 2012 surveys recorded 616 harbor porpoises, or 15 individuals/transects.

Tides & Current Speed –

In fall 2014, harbor porpoise abundance varied with tidal phase, current speed and direction. In total, 36 porpoises (97%) were observed during the flooding part of tidal cycle whereas 1 porpoise was seen during the ebbing period of the cycle. Within the flooding period, porpoise numbers were highest during the later phases, FF2 and SF2 (figure 14). Regardless of current direction, the majority of porpoises were observed during current speeds between 1-2 kts (figure 11).

The data from 2014 aligns with some patterns of abundance and tides in 2012 and 2013. In 2012, porpoises showed a similar preference for flooding tides as in 2014 but with a weaker signal (figure 16). In fall 2013, due to lack of sampling during ebbing tides, porpoises tidal direction preference could not be determined. Preference for tidal phase in 2012 and 2013 were in alignment with each other but differed from 2014 results. In 2012 and 2013 porpoises were most abundant during the middle phase of the flooding tide (figure 15, figure 16). In terms of interannual preference for current speed, 2013 data shows highest abundance of porpoises during medium to high current speeds of 1.5-3 kts (figure 12). In 2012, porpoises showed a slight preference for medium to high current speeds but overall were more evenly distributed across current speeds (figure 13).

Depth Preference –

In Fall 2014, harbor porpoises were more frequently seen in deeper parts of the SJC. A total of 30 porpoises were observed in the deep part of the channel and 7 porpoises in the shallow part of the channel (figure 17). This pattern was consistent regardless of the tidal phase or current speed (figure 18). Data from 2012 showed no significant difference in abundance between the two depths of the channel with 328 porpoises in the deep side and 374 porpoises in the shallow side (figure 19).

Discussion:

My finding of unusually high cetacean diversity in fall 2014 was unexpected given previous PEF trends, but is consistent with other outside reports in the region. Calambokidis (2011) has reported a distinct increase in sightings of unusual cetaceans in the Salish Sea during the last decade. Locally in the SJA, humpback whales are now seen through the fall and well into the winter (P. Green, pers. comm.) and sightings of Pacific white-sided dolphins have become more frequent (PWWA 2014). There is no general consensus about the causes of this change in cetacean species composition (Calambokidis 2011), but changes in oceanographic conditions and prey abundance have been speculated (Watts et. al 1985, Johnston 2005, Pierpoint 2008). Clearly, further study is needed to determine possible causes and whether this represents a short term perturbation or the beginning of a long term change.

The extremely low abundance of harbor porpoises this year was unforeseen given the general trend of porpoise population growth over the past decade (Calambokidis 2011, Teller 2012). Historically porpoise population numbers have fluctuated drastically in the Salish Sea. Once considered the most common cetacean in the Salish sea, during the 1970's porpoise numbers had dropped drastically verging on local extinction. The suspected cause of this decline was in part due to anthropogenic disturbances such as fishing gear entanglements, bycatch in gillnets, and contaminants (Raum-Suryan et. al 1998). With the aid of mitigation and rehabilitation efforts, harbor porpoise populations have risen substantially from 2007 through

2013 (WDFW 2009) and are once again considered the most commonly observed cetacean in the Salish Sea (Calambokidis 2011).

Causes for low porpoise abundance in 2014 are unclear but could be explained by a number of anomalous environmental conditions in the Salish Sea. Though Harbor porpoise numbers were low throughout the season, they were especially low later in the season after the fall transition in mid october. Fall transition, the oceanographic shift from upwelling to downwelling, between *R/V Centennial* cruises on October 14th and October 21st, brought unusually warm oceanic waters into the SJC raising the sea surface temperature up 5˚ celsius (G. Beatriz, pers. Comm.). The source of this warm water was a persistent anomalous "blob" of exceptionally warm water off the coast (OWSC Newsletter 2014). Warmer sea temperatures could have reduced plankton and therefore the forage fish that harbor porpoise prey on (Raum-Suryan et. al 1998, Zamon 2001, Zamon 2003, Pierpoint 2008).

The pattern this year suggests that long term variations in porpoise numbers may also correlate with large scale oceanographic patterns. For example, high numbers of harbor porpoises in SJC fall 2011 and 2012 correlated with cool la Nina conditions. Past research has studied the effects of these long term oceanographic cycles on seabirds and other marine mammals and could be deduced that the conditions would have similar effects on porpoises (Dedekoven et. al 2001).

Recent increases of other cetacean species in the SJC could also influence harbor porpoise abundance through competition or direct harassment. Pacific White-sided dolphins and bottlenose dolphins have been known to directly compete with harbor porpoises due to their similar feeding ecology and size (Spitz 2006). Considering their enormous consumption rates, even humpback whales could affect prey availability for harbor porpoises. Pacific white-sided dolphins have also been known to violently harrass harbor porpoises (Baird 1998). Recent increase in PWSD sightings in the SJ archipelago suggest that this species may be in the process of colonizing the area (P. Green, pers. comm). Transient killer whales, that feed exclusively on porpoises and other marine mammals (Saulitis 2000), have also been seen more frequently in the SJA in recent years.

Anthropogenic impacts such as fishing gear entanglements, bycatch in gillnets, contaminants, and acoustic pollution were previously implicated in harbor porpoise declines (Raum-Suryan et. al 1998, Nowacek et al. 2007). Whether these currently affect harbor porpoises is not known, but high levels of contaminants have been reported in other cetaceans of the salish sea (Krahn et al. 2007). Even as minor effects, these impacts could influence populations already depressed by other environmental factors.

The finding that the harbor porpoise, a top predator, is affected by tides is consistent with past results from research both in and outside of the PEF program (Raum-Suryan et al. 1998, Zamon 2001, Zamon 2003). Preference for flooding tides and faster tidal current speeds this year is consistent with the tidal coupling hypothesis described by Zamon (2003). The tidal coupling hypothesis explains that tides and current interact with the bathymetry of an area creating rips and jets that impact zooplankton distribution and abundance. These predictable changes in plankton influence where foraging fish will be located and thus where predators will congregate. Additional outside research has shown this relationship pattern to be true for harbor porpoises (Raum-suryan et. al 1998).

In fall 2014, harbor porpoises preference for deeper portion of the channel aligns with previous outside research (Raum-Suryan et al. 1998). Channels with narrow steep shelves act as a bottleneck where accelerated tidal currents force plankton into the water column and transports them through the channel. Steep shelves also act to concentrate plankton in areas of upwelling where forage fish feed on them, thus attracting piscivorous predators (Watts et al. 1985, Pierpoint 2008). Harbor porpoises would be expected to aggregate along cliff faces and in the central parts of the deep channels as they pursue their planktivorous prey. In more gradually sloping channels plankton are more widely dispersed and are not known to aggregate as densely in areas with shallower and flatter terrain. In addition, for porpoises, swimming in the deeper parts of the channels is more energy efficient because it has less turbulent waters than the more shallow waters (Watts et al. 1985).

Differences in observed porpoise/tide/depth relationships between 2014 and 2012 may reflect differences in overall porpoise abundance between the two years. The weaker relationship in 2012 of porpoise abundance and tides was found for virtually every fine-scale variable including tidal current direction, current speed and water depth. Perhaps the most likely explanation is that 2012 was a year of much higher productivity and prey abundance. This is consistent with the finding of much higher porpoise abundance in the region. In years of high prey abundance, porpoises may not need to be as selective in their feeding times and locations. Prey may be more widely dispersed and available in all habitats, and porpoises may be able to feed throughout all tidal conditions.

Conclusion:

It has been proposed that the harbor porpoise is a good indicator species for the health of the Salish Sea ecosystem. To most effectively use the harbor porpoise as an indicator species, more studies like mine of porpoises at various spatial and temporal scales are critical. For example, this year's finding of low abundance may be a one-time phenomenon or a start of a more long-term decline. Also, based on three years of PEF small-scale studies it's clear that porpoises are influenced by fine scale tidal factors. Understanding these complex relationships is vital for knowing when and where to monitor porpoises. My data indicated it is important to take into account annual variation in porpoise abundance when predicting these relationships.

Also interesting this year, we found more supporting evidence for a continuing shift in cetacean community composition in the SJA. Although this is consistent with other studies in the region, it is too early to tell if this is a widespread shift associated with large scale climate change, especially given the large ranges and scales cetaceans operate at. More consistent surveys of cetaceans in the Salish Sea region would allow us to follow the population trends and look for connections with long-term oceanographic cycles such as El Nino Southern Oscillation or Pacific Decadal Oscillation. Only by further understanding these patterns can we best determine which changes are ecologically natural and which are related to anthropogenic activities and in need of mitigation.

Acknowledgements

I would like to thank my professors Dr. Breck Tyler, Dr. Jan Newton, Dr. Matt Baker along with my graduate student assistant Rebecca Guenther for their instruction and assistance with the planning and implementing of my project. Specifically, I would like to thank my advisor Dr. Breck Tyler for all of his patient and calm guidance throughout my project and for paper editing assistance. I would like to thank my volunteer Observers Gabriela Beatriz, Sally Milligan, Bryan Antonio Briones Ortiz, Kailee Bynum, Jessamyn Johnson, Emily Burke, Olivia Graham, Laura Kostad, Zack Bivins. Without these generous volunteers taking time off from their own projects and free time I would not have been able to conduct my small boat surveys. I would also like to thank all of my PEF peers and other FHL peers for your constant support and entertainment throughout my project and this quarter.

Tables and Figures:

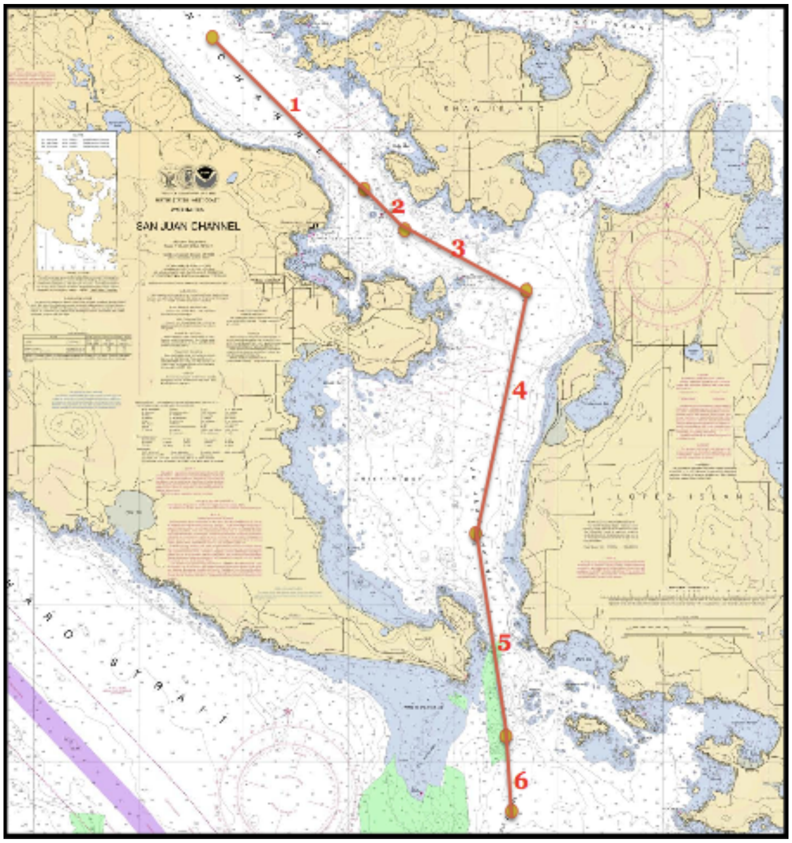

Figure 1. Zones of the San Juan Channel transect (PEF), zone 1 is in the north and Zone 6 is in the south (Vermerie 2010).

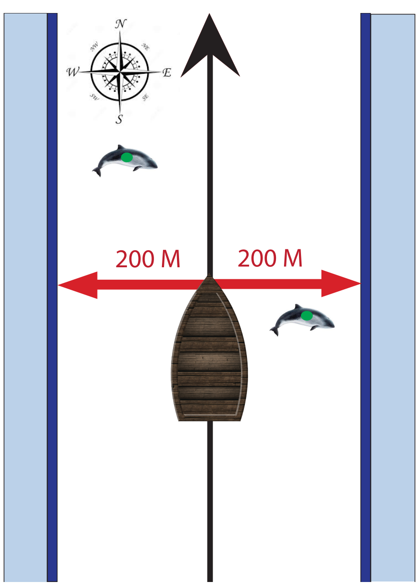

Figure 2. Diagram of the strip transect method. Animals are recorded if they fall within 200 meters on either side of the boat.

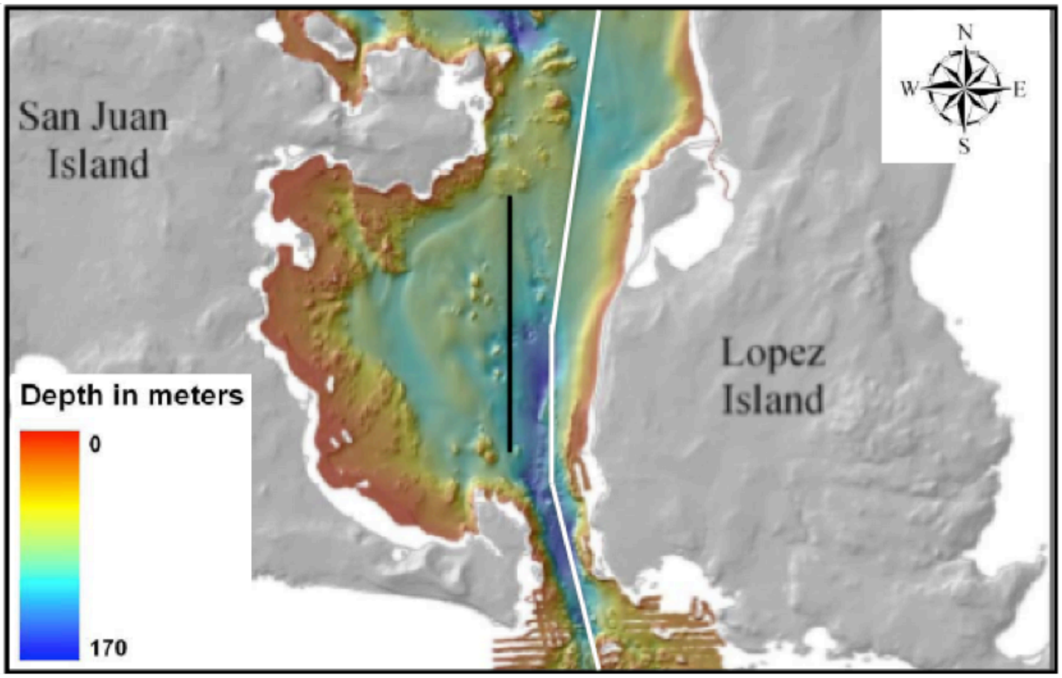

Figure 3. fine-scale survey transect (black line) located in Griffin Bay. One side of the transect represents the deep side of the channel and the other side represents the shallow. The fine scale transect runs along side zone 4 of the large scale *R/V Centennial* transect (white line). (courtesy Gary Greene)

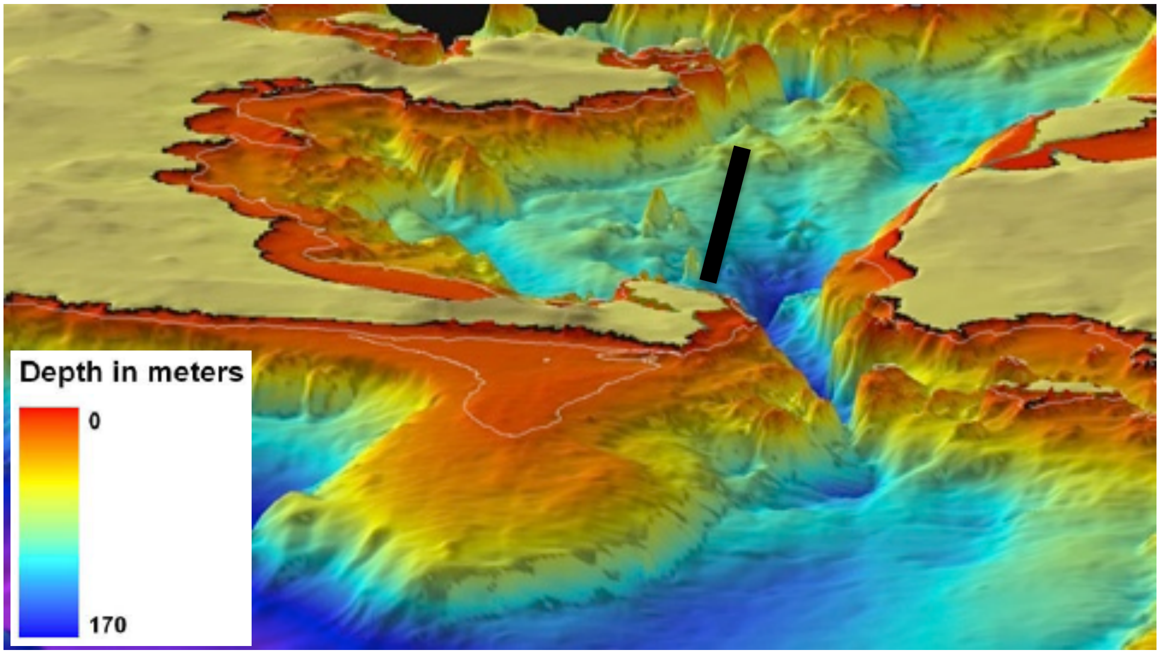

Figure 4: Small boat transect (black line) located in Griffin Bay. Right side of transect is the deep portion of the San Juan Channel, along the left side is the shallow portion of the channel. (courtesy Nearshore Habitat Program)

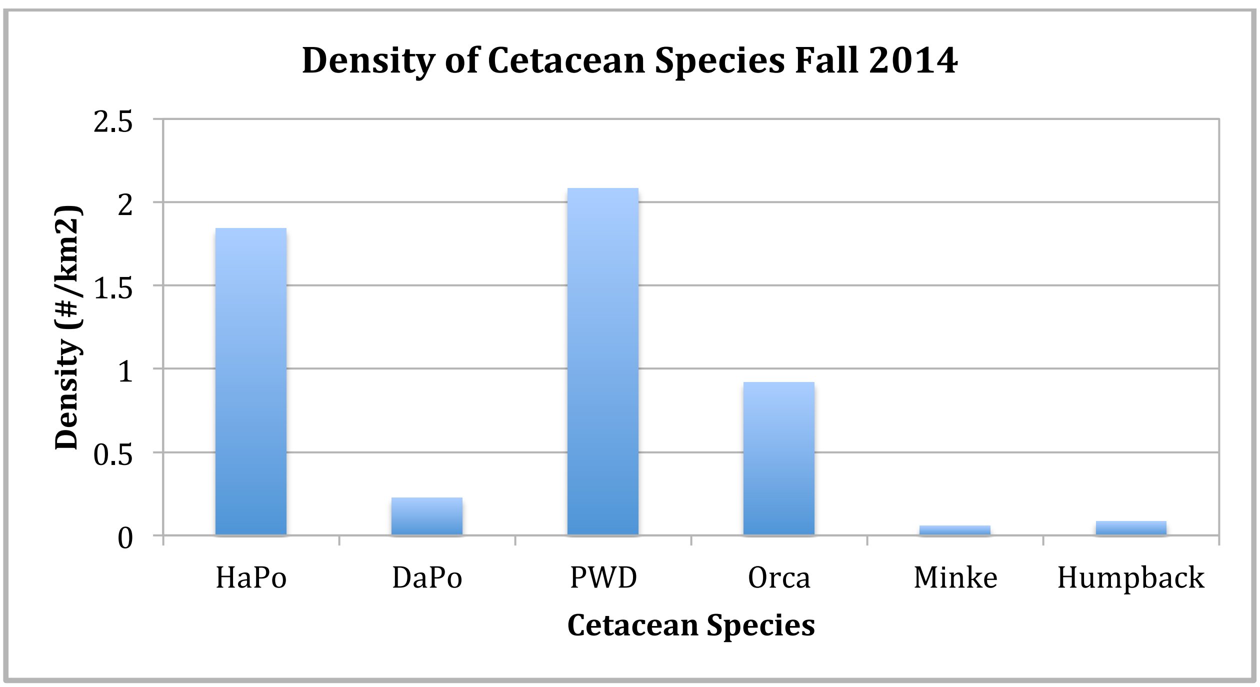

Figure 5. Density of cetacean species found in the San Juan Channel during large scale surveys in Fall 2014.

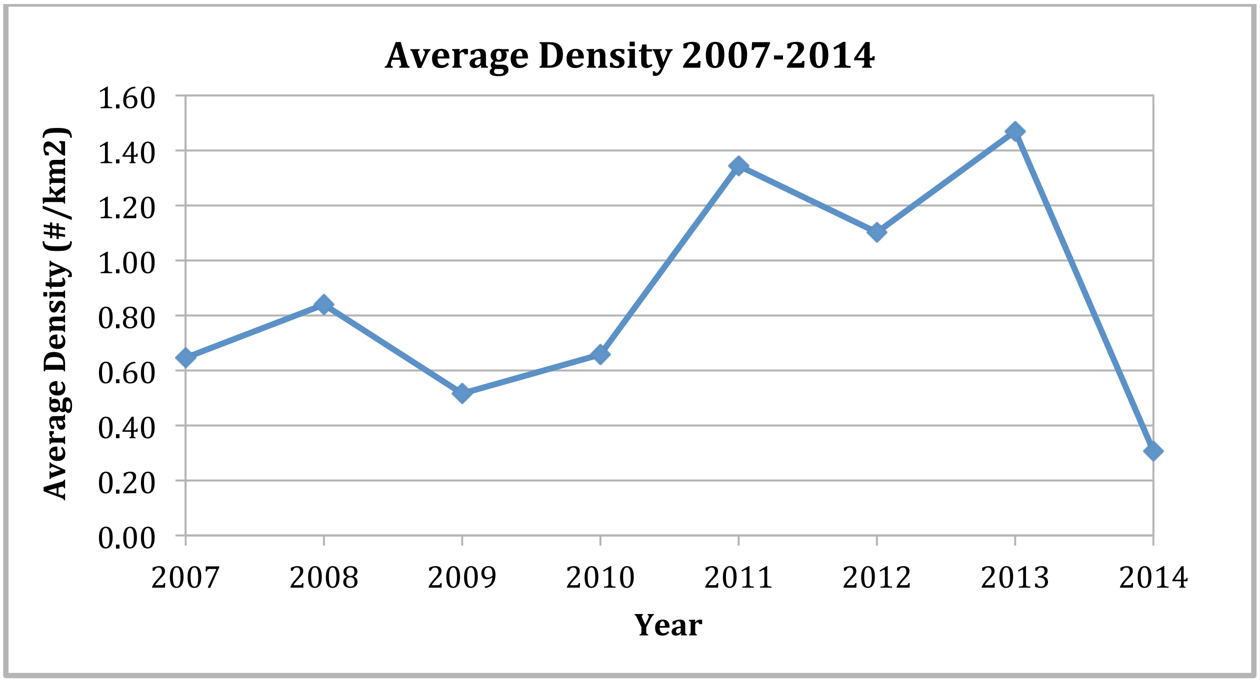

Figure 6. Average density of harbor porpoises per year in the San Juan Channel from 2007 to 2014 during large scale *R/V centennial* cruises.

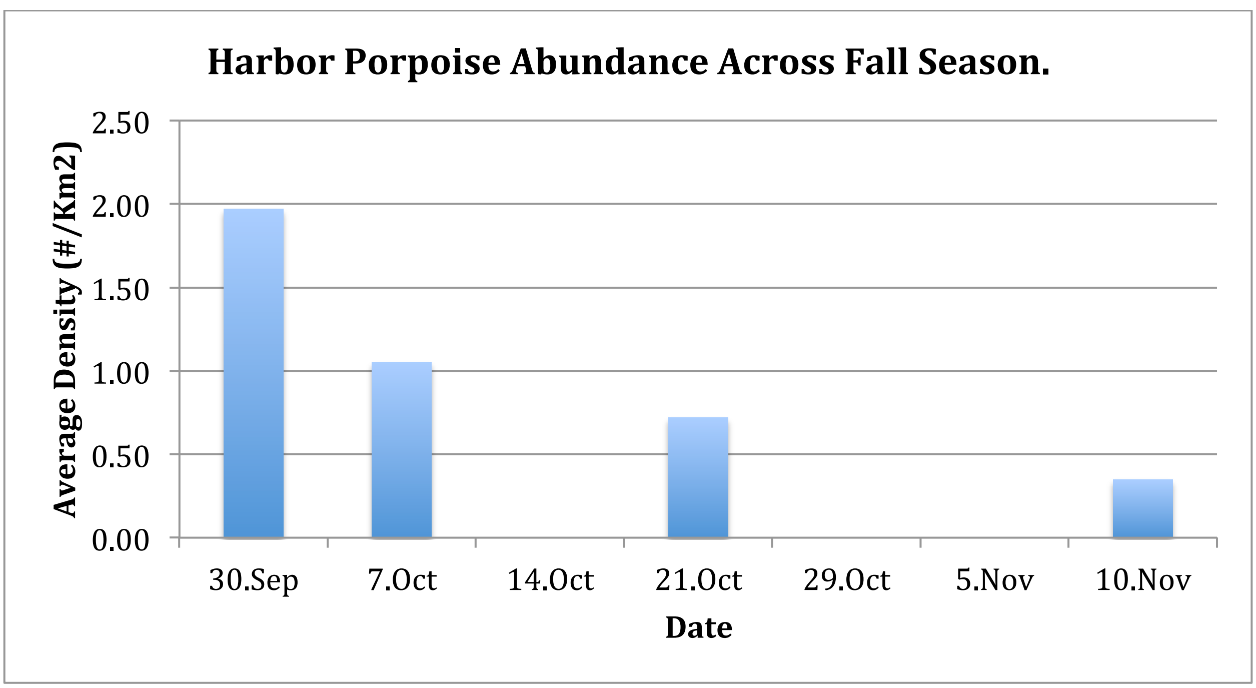

Figure 7. Harbor Porpoise Abundance per each of the seven large scale surveys across the fall season in 2014.

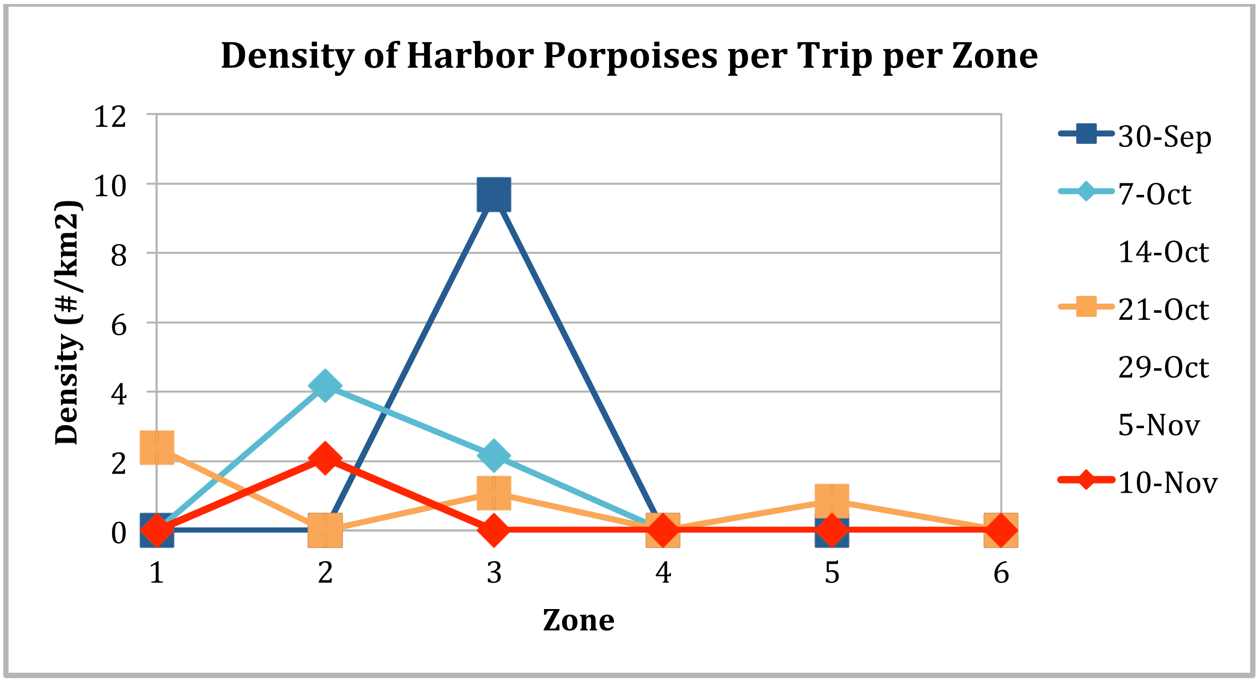

Figure 8. Density of harbor porpoises per trip per zone across the seven large scale surveys of fall 2014.

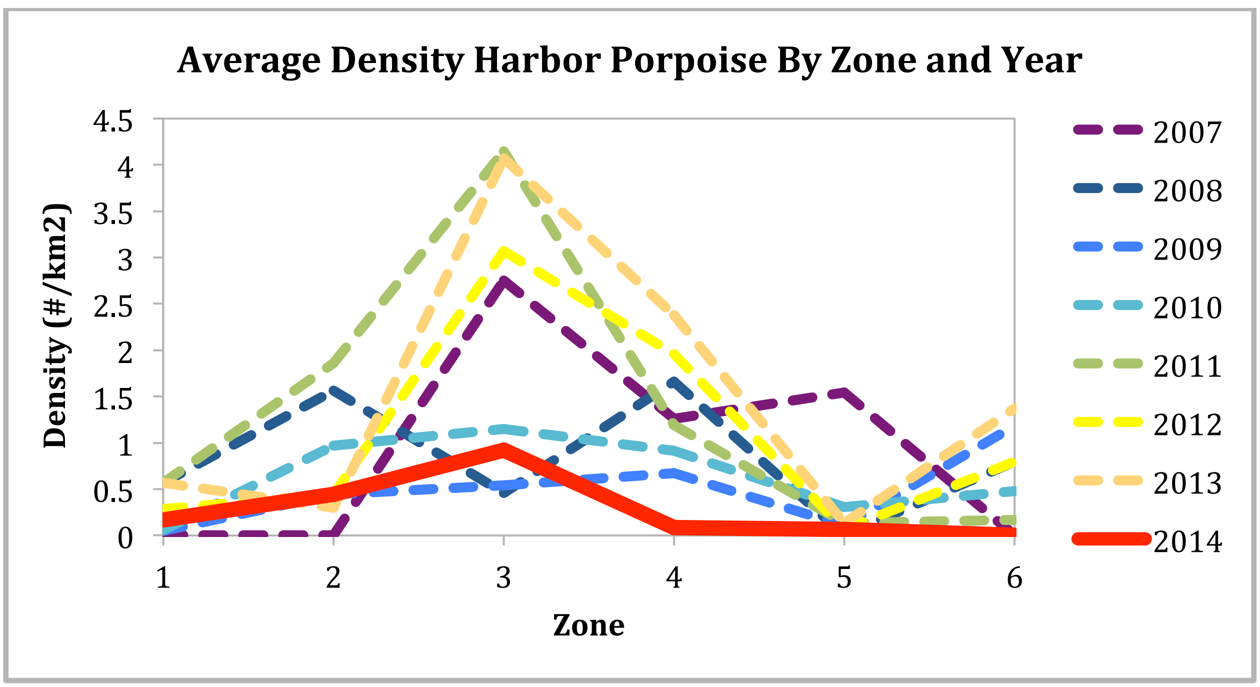

Figure 9. Density of harbor porpoises per trip per zone across the eight years of large scale surveys from 2007 to 2014.

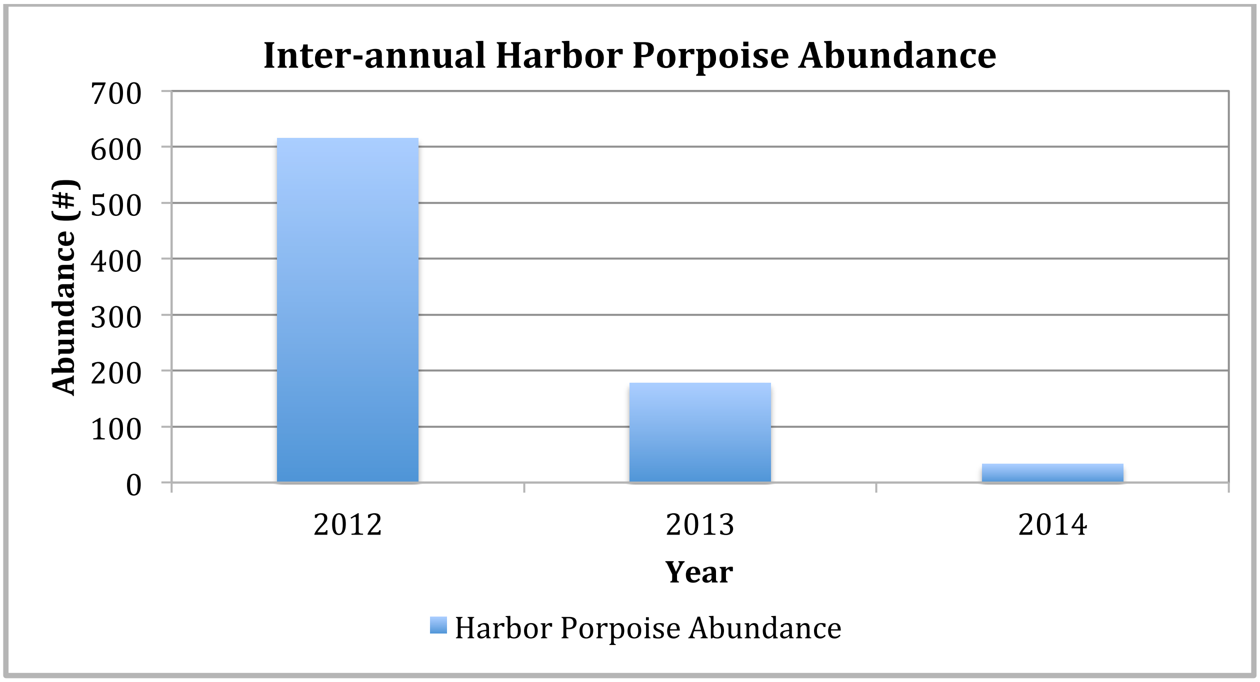

Figure 10. Inter-annual abundance of harbor porpoises from 2012-2014.

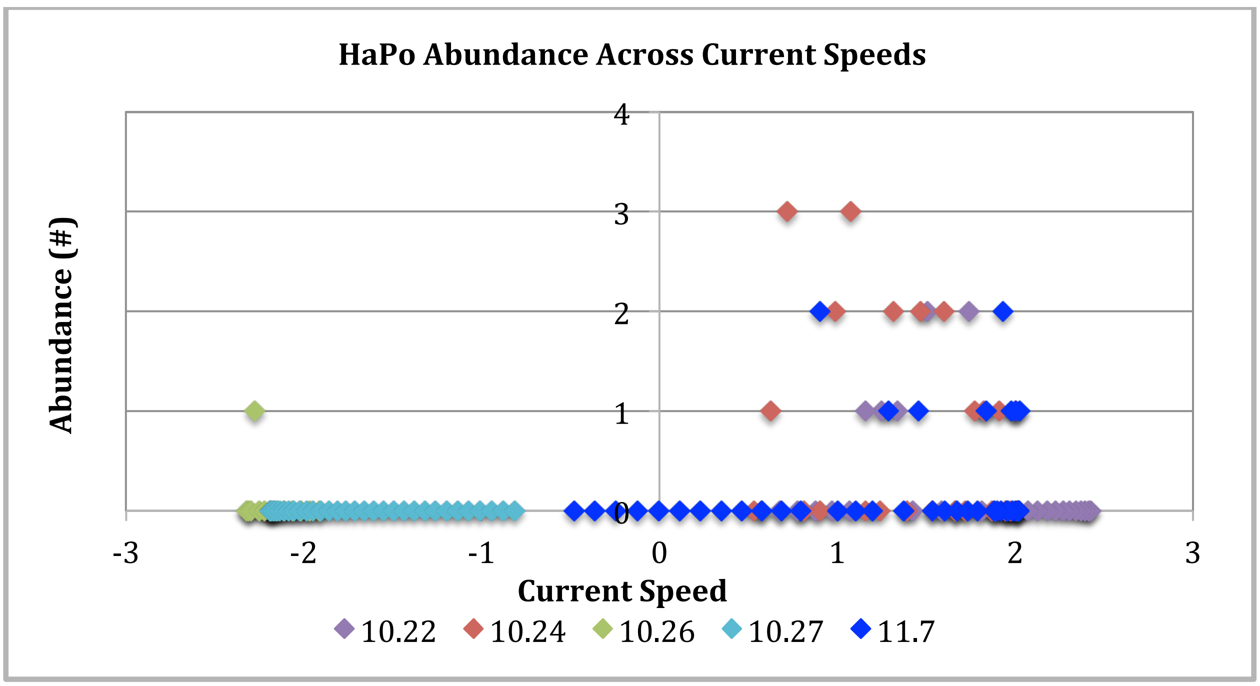

Figure 11. Abundance of harbor porpoises across current speeds per date of fine scale surveys in fall 2014. Zeros represent that that current speed was sampled with no porpoises found. If there is no marking, that current speed was never sampled.

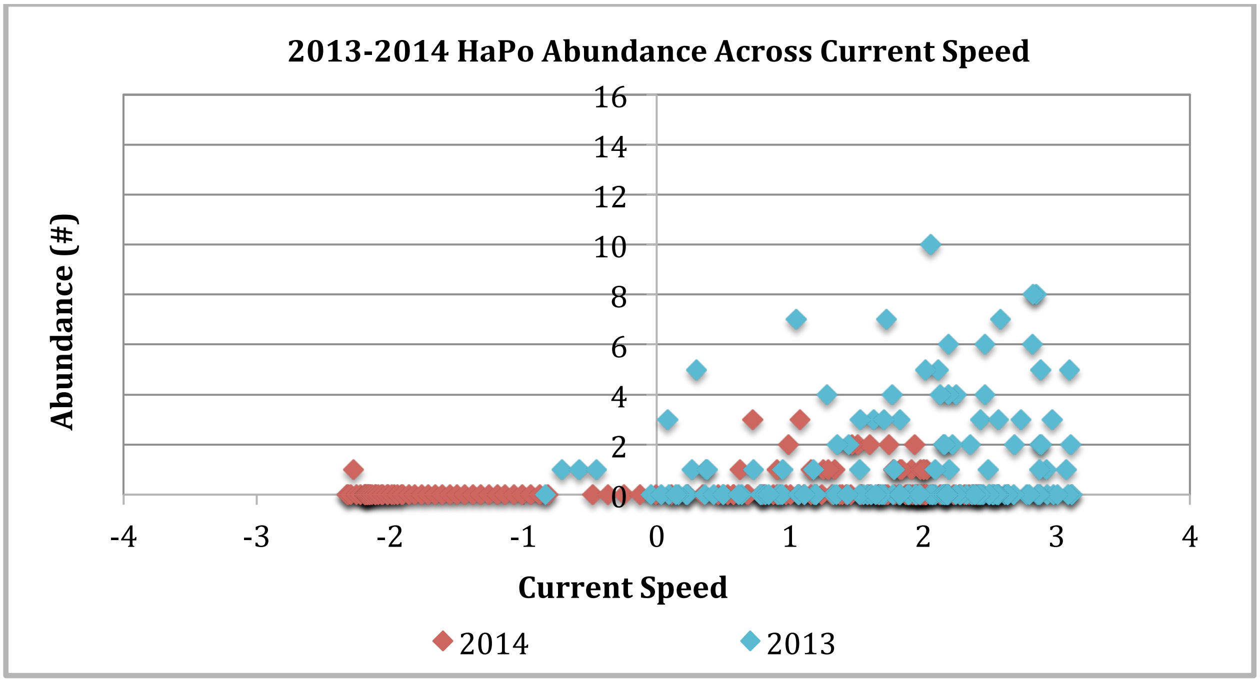

Figure 12. Abundance of harbor porpoises across current speeds during 2014 and 2013 fine-scale surveys. Zeros represent that that current speed was sampled with no porpoises found. If there is no marking, that current speed was never sampled.

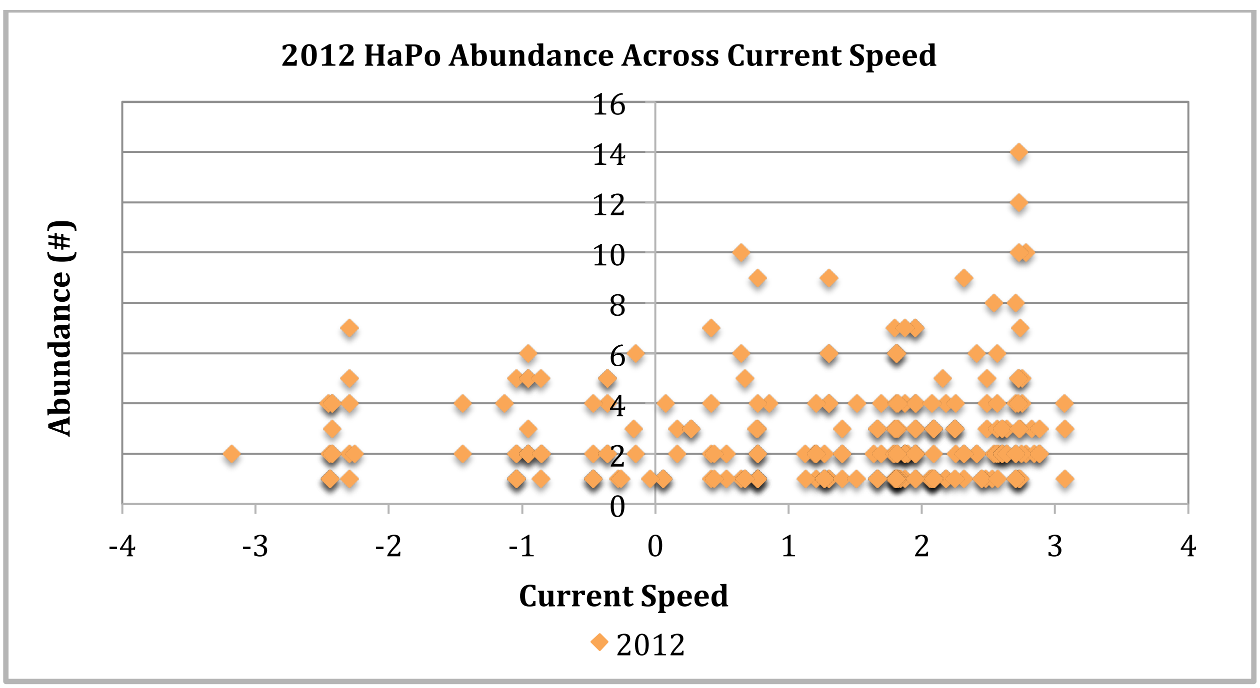

Figure 13. Abundance of harbor porpoises across current speeds during 2012 fine-scale surveys.

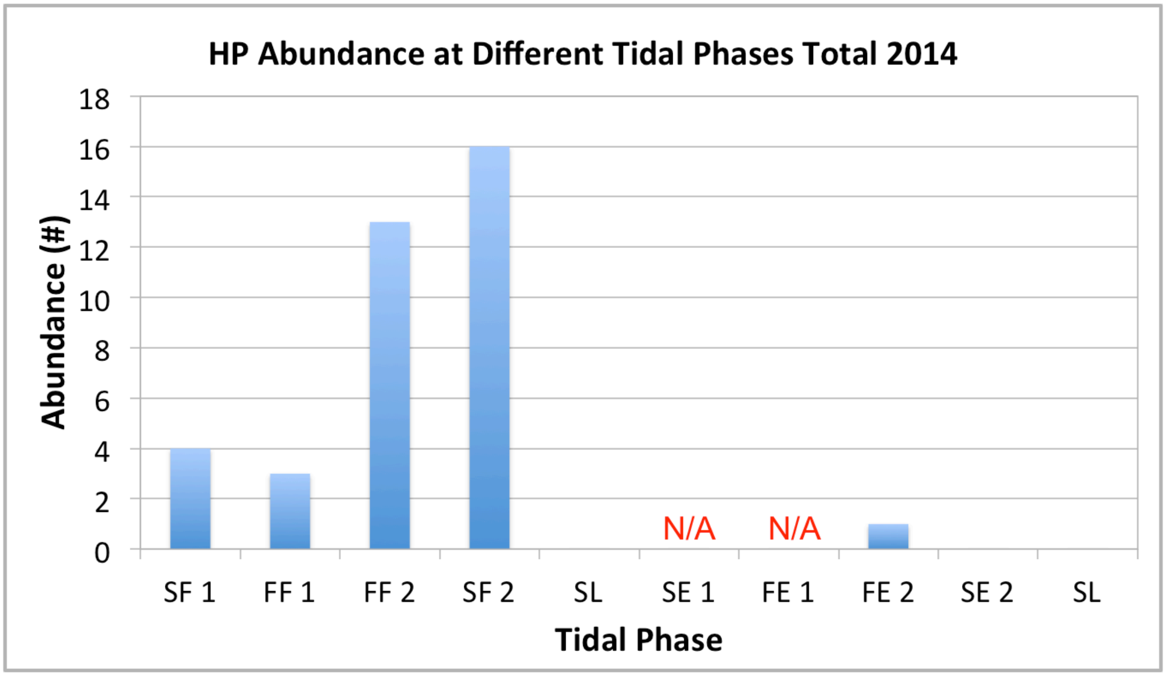

Figure 14. Abundance of harbor porpoises across tidal phases in Fall 2014. 1 and 2 represent the first or second half of a tidal phase respectively. The tidal phase is divided by current speeds with flooding phases being SF=.5 kts to 1.5kts and FF= ≥1.5 kts; Ebbing phases being SE= -.5 kts to -1.5 kts and FE= ≥-1.5 kts, and slack being SL=-.5 kts to .5 kts. N/A represents that tidal phase was never sampled.

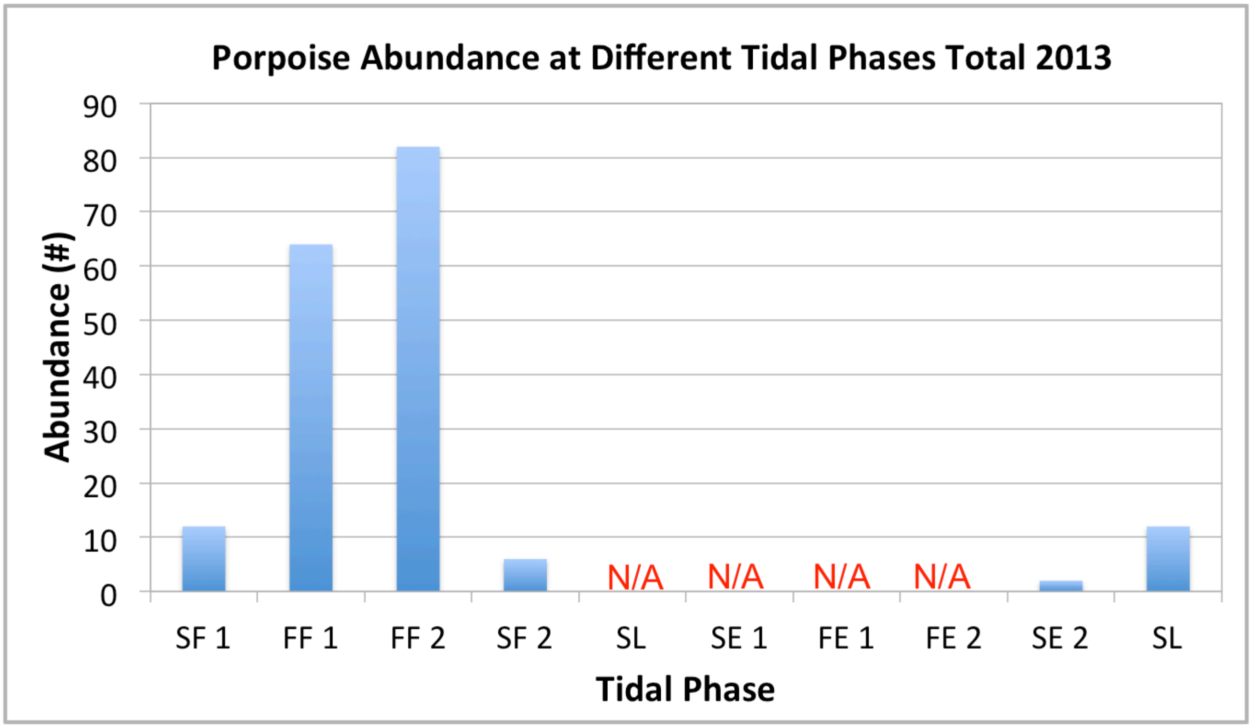

Figure 15. Abundance of harbor porpoises across tidal phases in Fall 2013. 1 and 2 represent the first or second half of a tidal phase respectively. The tidal phase is divided by current speeds with flooding phases being SF=.5 kts to 1.5kts and FF= ≥1.5 kts; Ebbing phases being SE= -.5 kts to -1.5 kts and FE= ≥-1.5 kts, and slack being SL=-.5 kts to .5 kts. N/A represents that tidal phase was never sampled.

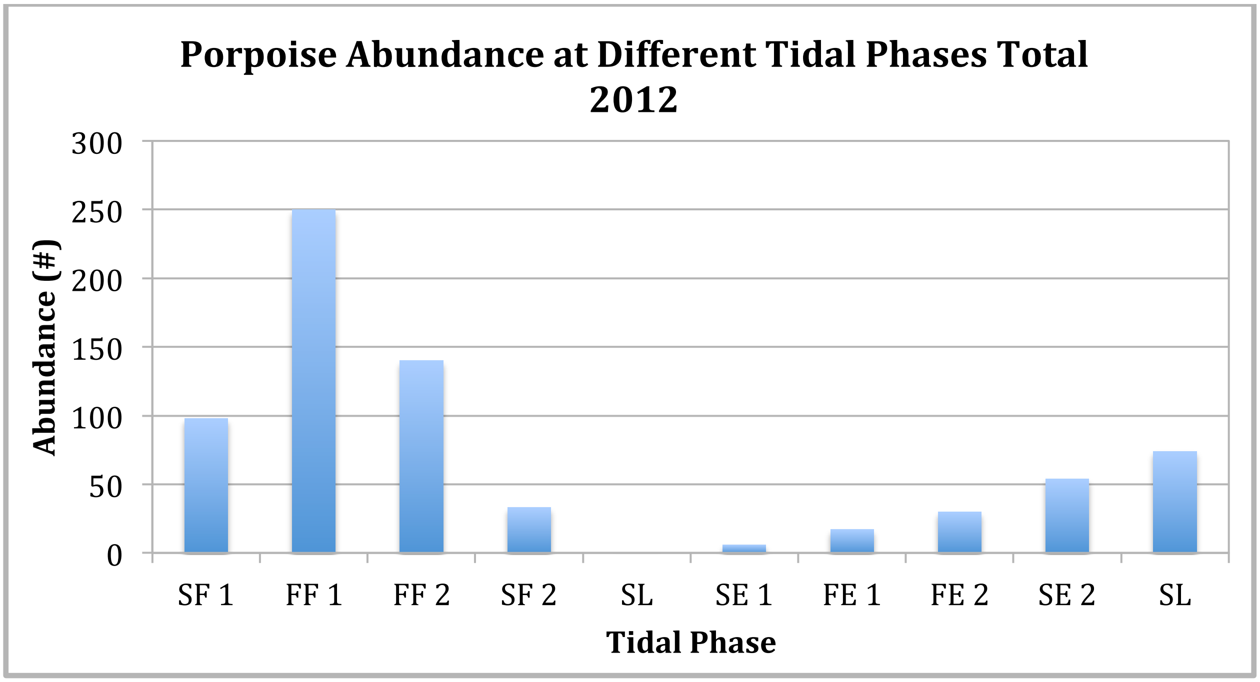

Figure 16. Abundance of harbor porpoises across tidal phases in Fall 2014. 1 and 2 represent the first or second half of a tidal phase respectively. The tidal phase is divided by current speeds with flooding phases being SF=.5 kts to 1.5kts and FF= ≥1.5 kts; Ebbing phases being SE= -.5 kts to -1.5 kts and FE= ≥-1.5 kts, and slack being SL=-.5 kts to .5 kts.

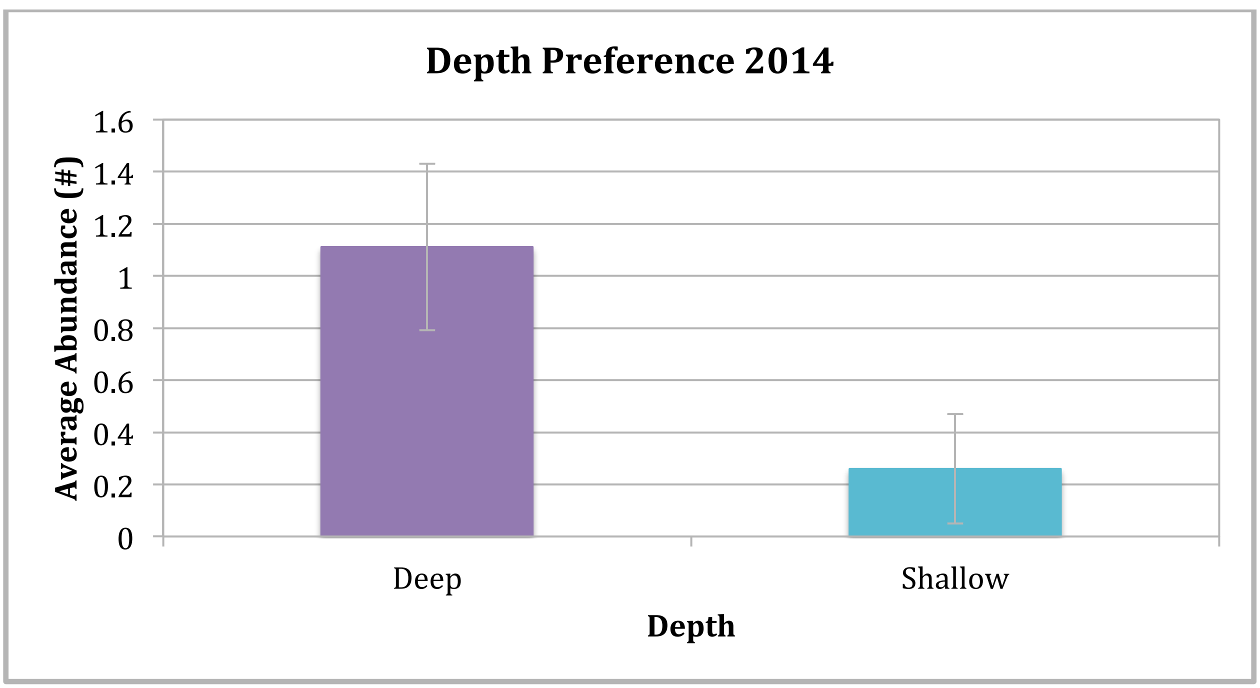

Figure 17. Abundance of harbor porpoises in deep vs shallow depths of the San Juan Channel in fall 2014. Error bars represent confidence intervals.

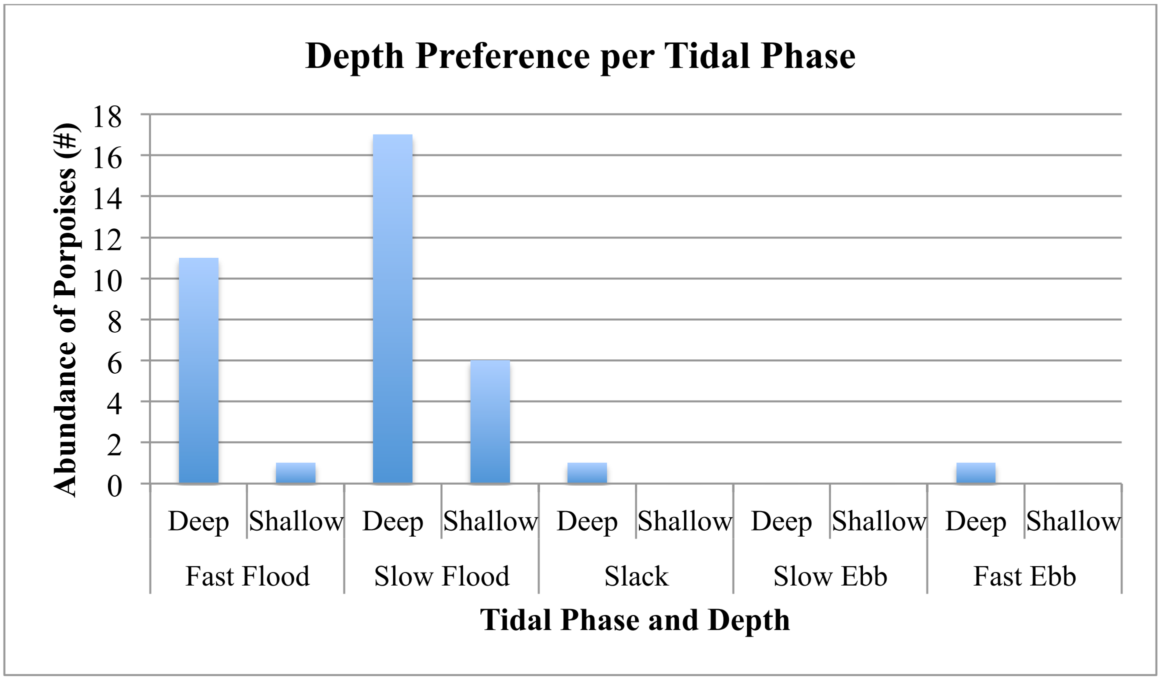

Figure 18: Abundance of harbor porpoises in deep vs shallow depths and across different tidal phases. The tidal phase is divided by current speeds with slow flood =.5 kts to 1.5kts and fast flood= ≥1.5kts; Ebbing phases being slow ebb= -.5kts to -1.5kts and fast ebb= ≥-1.5kts, and slack = -.5 to .5kts.

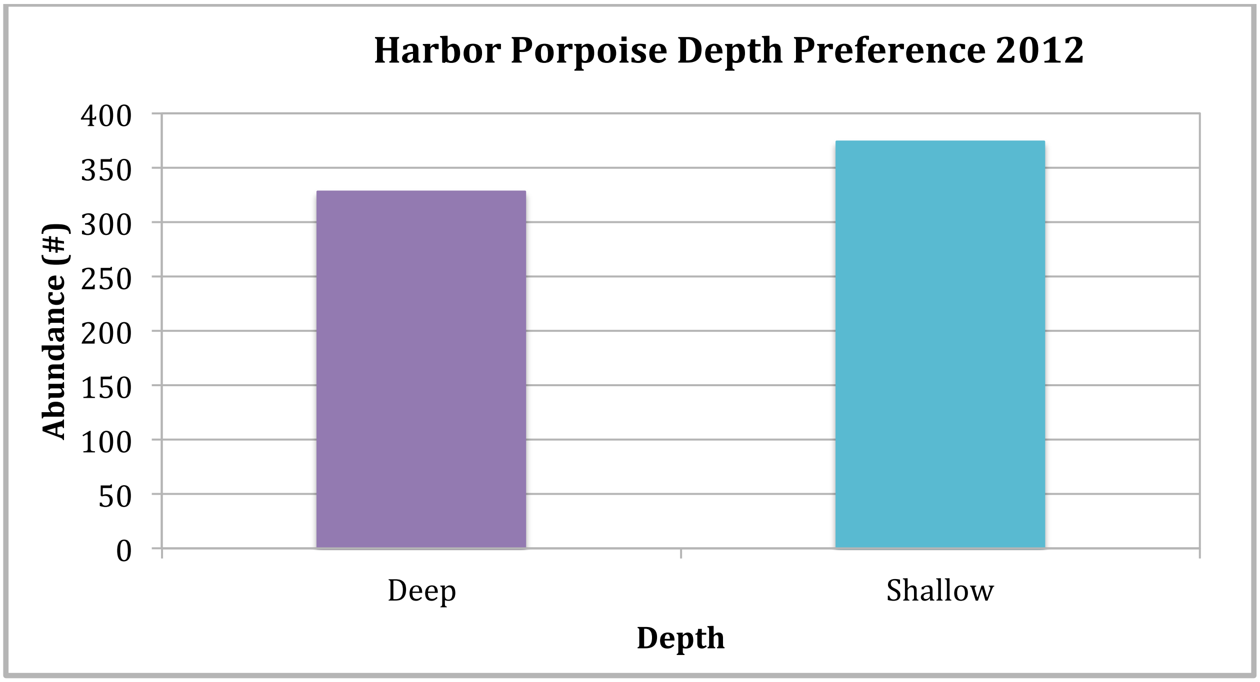

Figure 19. Abundance of harbor porpoises in deep vs shallow depths of the San Juan Channel in fall 2012. Error bars represent confidence intervals.

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