Distribution and Abundance of Porpoises In the San Juan Channel: Effects of Bathymetry and Tides

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Abstract

The San Juan Archipelago is a dynamic cluster of islands supporting seven species of cetaceans including the harbor and dall's porpoises. Under recognized in the San Juan Archipelago conservation and better management of these species are required. Harbor porpoises were seen in higher densities than dall's porpoises concurrent with past data. Supported by the habitat preference of each species. Densities of harbor porpoises were highest in the central part of the San Juan Channel and densities of dall's porpoises were not a regular pattern observed. The bathymetry in this section (3 and 4) described by a sudden change from deep (~ 165 m) to shallow (~70 m) water depth effects turbulent mixing and prey aggregation dependant on current speed and direction. Harbor porpoise densities changed considerably due to this effect. Harbor porpoises densities changed when considering tidal factors. Highest densities of harbor porpoises were counted during fast flood (3.02/km^2) and fast ebb (1.75/km^2). Increased density with increased current speed was observed over 67% of cruise days.

Introduction

The San Juan Archipelago is a dynamic cluster of islands in the Salish Sea that supports seven species of cetaceans. Two species are present throughout the San Juan Archipelago (SJA) year round. The dall's porpoise (*Phocoenoides dalli*) and the harbor porpoise (*Phocoena phocoena*) are prominent species of this area. The harbor porpoise has a solid gray body weighing up to 200lbs with a length up to 6ft. The dall's porpoise is black with white flanks and a white tip to the tail and dorsal fin, weighing up to 450lbs with a length up to 8ft. These porpoises vary slightly in feeding ecology, while both species of porpoises feed on forage fish (ie. herring and capelin) and squid; the dall's porpoise also feed on mesopelagic fish and squid found in deeper waters (Friday et al. 2012). The difference in feeding ecology results in a difference in distribution throughout the SJA. Here the dall's porpoise is more commonly scene in the deeper waters such as Haro Strait where the harbor porpoise is more commonly scene in shallow waters such as the San Juan Channel (SJC) (Colombokidis et al 2004).

The population statuses of these species are not precisely clear throughout their range locally. Global populations of harbor porpoises appear stable, while dall's porpoises are listed as threatened by the International Union for Conservation of Nature and Natural Resources (NOAA). In the Salish Sea harbor populations were thought to have declined in number and density in the 1990s and early 2000's(Osmek et al 1996, Keple 2002). However, in 1998 reports of density increases of harbor porpoises were observed (Raum-Suryan and Harvey 1998). Part of the problem behind the declines of harbor porpoises may have been by-catch in the commercial gill net fishery where 50%-75% of cetaceans caught in these nets were Harbor porpoises (Hall et al. 2002). In recent years however, harbor porpoise numbers in the Salish Sea appear to be increasing (Calombokidis 2011). This is interesting considering the many reports of declines of other marine species during the same time (Rothaus et al 2008, Burger 1995). Even less is known about dall's and harbor porpoise populations in the San Juan Channel. Past studies on porpoises in the SJA have found contradicting estimates of population densities (Osmek et al 1996, Raum-Suryan and Harvey 1998, Calombokidis 2004, and Keple 2002). The Pelagic Ecosystem Function (PEF) Apprenticeship at Friday Harbor Laboratories (FHL) are the only other reports of populations of harbor and dalls' porpoises that are relatively stable for the SJC through the fall for 2007-2011 (Vermeire 2010). Clearly additional survey work is needed to better understand population trends and make management decisions.

The distribution of harbor and dall's porpoises in the SJA are determined by their ability to find food (Keple 2002). In the SJA prey availability is strongly influenced by tides and bathymetry (Zamon 2001). Flooding tides have shown positive aggregations of piscivorous predators (Zamon 2003). Tides effect the bathymetry by increasing turbulent mixing and concentrations of planktonic organisms, nutrients, and inorganic particles (Iwamae 2012). Clearly an understanding of the relationship between tides, bathymetry and population abundance would allow for better understanding of their behaviors regarding spatial preference. Previous PEF apprentices have tried to determine this relationship between population abundance and tides. The coarse spatial and temporal scales had mixed results. Studies of these factors at a finer scale might be more useful when characterizing the relationship porpoises have with tides and bathymetry.

The purpose of the research presented in this paper was to advance what is known about porpoises in the San Juan Channel. Specifically, I determined distribution and abundance for fall 2012, compared these findings with those from previous years (2007-2011), studied the effects of bathymetry and tidal factors such as, current speed and direction, and tidal phase at small spatial and temporal scales.

Methods

Strip transects were used in both the large transect through the San Juan Channel and the small transect through Griffin Bay (fig 1).

San Juan Channel Transect

Using FHL R/V Centennial transects were done on September 28th, October 10th, 17th, 23rd, 30th, November 7th, and 13th. Starting at North station (48° 35'N, 122° 59.57'W) traveling south on transect to South station (48° 25'N, 122° 56.75'W). Once arriving at South station the vessel is turned around and transected from South station to North station. The total length of the transect is 21.11km^2 divided into six zones based on the bathymetry of the transect with the zones starting coordinates and areas listed;

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

While on transect we had a minimum of one recorder and one observer on the port and starboard side of the bow recording the number and species of porpoise scene per minute, per zone, per transect within 200m of either side of the vessel. The densities per zone are then calculated by:

(number of individuals)/(zone area) = Density

Griffin Bay Transect

Using FHL R/V Bufflehead transects were conducted on the following dates:

October 11th: 3 transects

October 22nd: 3 transects

October 24th: 7 transects

October 25th: 8 transects

October 26th: 8 transects

October 28th: 10 transects

October 29th: 8 transects

November 9th: 7 transects

Some days had more or less transects due to weather and available light to affectively conduct the survey. Transects were done back-to-back approximately 30 minutes apart. Transects started at the south end of Griffin Bay (48° 28,256'N, 122° 57,517'W) then traveled to the north end of Griffin Bay (48° 30,250'N, 122° 57,837'W). The total length of the transect is 4 km and the area is 1.6 km^2. There was one recorder and one observer on the port and starboard side of the vessel recording the number and species of porpoise scene per minute, per transect within 200m of the vessel. The densities per transect and per side of the boat are then calculated by:

(number of individuals)/(transect area) = Density

Results

Abundance

During Fall 2012, harbor porpoises were almost 6x more abundant than dall's porpoises. The mean density of harbor porpoises was 1.00 +/- 1.25 per km^2, whereas dall's porpoise density was 0.16 +/- .26 per km^2 (table 1). Harbor porpoise abundance varied between cruises. Highest abundance was observed on October 30th (25.13 per km^2), all other cruise abundances remained below 5.57 km^2 (fig. 2). Alternatively, dall's porpoises were only seen two times (fig. 3).

Harbor porpoise abundance this year was comparable to 2011, but both were higher than all past years. In 2011 and 2012 density was greater than 1.00/km^2, whereas from 2007-2010 densities were lower, ranging from .52/km^2 - .84/km^2. In contrast, dall's porpoise abundance this year was comparable to previous years. In fact, dall's porpoise numbers have been very consistent ranging from 0/km^2 - .16/km^2 (fig. 4).

Distribution

Harbor porpoises did not show an even distribution throughout the channel during Fall 2012. Highest mean numbers were counted in zone 3

(3.07/km^2) and zone 4 (1.96/km^2). In other more northerly and southerly zones harbor porpoise density did not exceed .79/km^2. Dall's porpoises were seen irregularly and did not show a zonal pattern. They were only recorded in zones 2 and 4 once (fig. 5).

Distributional patterns in 2012 were generally similar to those in previous years, with highest numbers in the central zones. During the period of 2007-2012 harbor porpoise density was greater than 1/km^2 in zones 3 and 4, about .75/km^2 in zone 2, and less than .6/km^2 in the other zones. During this same period dall's porpoises were recorded in all zones, but densities never exceeded .15/km^2 (fig. 6)

Abundance & Current Speed

Even in the areas of highest density (zone 3 and 4) there was high variability in harbor porpoise densities within day and day-to-day. During 14 transects harbor porpoises were encountered 11 times, but high densities (> 10/km^2) were observed only 3 times. This means that harbor porpoises were not seen on 21% of transects. The observed variability in abundance did not appear to correlate with tidal current speed and direction. Three of the four highest counts were seen during fast currents (1 fast flood, 2 fast ebb). However, on other transects during the same current speed and direction density was much lower (fig. 7).

Depth Preference

Harbor porpoises did not show a preference for depth (shallow or deep) when not accounting for current speed and direction. The density of porpoises counted at shallow depth was marginally higher than the density counted at deep depth (fig. 8). However, when harbor porpoise counts were separated by current speed and direction there was a variation in depth preference. Highest densities of harbor porpoises were counted during fast flood (3.02/km^2) and fast ebb (1.75/km^2), whereas, almost no porpoises were counted during slack. Fast flood densities varied by depth where shallow was higher at 1.85/km^2 and deep was lower at 1.17/km^2. Fast ebb densities varied less by depth where deep was higher at 1.01/km^2 and shallow was lower at 0.74/km^2. Fast flood shallow is significantly higher than all densities except for fast flood deep and fast ebb deep. Shallow depth during fast ebb, slow ebb, and slow flood were the same (0.74-0.75/km^2) (fig. 9).

Density Across Time

Densities of harbor porpoises were variable over time during changing current speed. From all cruise days 67% showed densities that increased with increasing current speed. This increase was followed by a distinct decrease in density. There were two cruise days (Oct. 29th and Nov. 9th) where more than one transect was conducted over an ebbing tide. October 29th showed a decrease in density over decreasing current speed, whereas, November 9th showed relatively no increase in density with increasing current speed. In contrast, on October 26th there was minimal change in density through an increasing current speed during a flood tide (fig. 10).

Discussion

Abundance

The finding that in Fall 2012 harbor porpoises were almost 6x more abundant than Dall's porpoises was not surprising; this similar pattern was also seen every year from 2007-2011. This is consistent with known habitat preferences for the two species. Harbor porpoises prefer shallower water, whereas dall's porpoises are seen more commonly in deeper water found elsewhere around the SJA (Colombokidis et al 2004). Dall's porpoises moving inshore and southward in winter, and offshore and northwards in the summer and fall have been documented (Pike & MacAskie 1969, Leatherwood et al. 1982). It is thought that harbor porpoises do not demonstrate a similar migration pattern (Barlow 1988, Gaskin 1992). Porpoise habitat preferences and movement patterns probably reflected prey preference and availability. The presence of dall's porpoise in the shallower water in the SJC was more likely because they were passing through the channel to feeding sites elsewhere.

Our observations that harbor porpoise populations have increased in SJC in 2011 and 2012 are consistent with reported numbers elsewhere in the region (Calamobokidis 2011). This increase might be due to several factors. The lower abundances found in earlier years (2007-2010) could be a reflection of prior population declines in the Puget Sound area (Osmek et al. 1997). The higher numbers in 2011 and 2012 could have indicated that the local population has grown or that it was augmented by the arrival of other individuals. Poor conditions in coastal waters may have encouraged individuals to move towards inland waters such as the SJC. Some researchers believe that harbor porpoise populations as a whole have increased to near carrying capacity in the past decade (Calambokidis 2011). Given the declines in many species this increase in hp is suprising and will be interesting to follow in future years.

The extremely high number of harbor porpoises on October 30th was unexpected. This might be explained by higher ebb tidal exchanges the few days prior and during the cruise resulting in ideal feeding conditions compared to some of the other survey dates. Yet, October 17th had the highest ebb tidal exchange, but a much lower porpoise density. This event was the highest density ever reported of harbor porpoises in the SJC during fall (PEF unpublished data). Oddly, no dall's porpoises were observed on this date.

Distribution

Vermeire (2010) concluded that porpoise density positively correlated with the distribution of their pray. The fact that, porpoise density was highest in zones 3 and 4 every year from 2007-2012 indicated that these zones have unique features that led to foraging opportunities. Generally these zones are shallower and wider than other zones. More importantly this part of the channel contains a slanted ledge going from 70 m flat to 165 m deep channel. The deeper area connects to a deep ravine that leads to the Strait of Juan De Fuca. This results in a 'bathymetric effect' where an increase in bottom roughness (ie. the slanted ledge) creates variation in turbulent mixing during different tidal stages. Turbulent mixing causes a displacement of water and the planktonic organisms, nutrients, and inorganic particles in the water column (Iwamae 2012). Where there is an increase in turbulent mixing there is an increase in plankton that is pray for forage fish (Pereira 2012, Bailey 2012) (fig. 11). The forage fish interns attract porpoises to feed. This process was likely responsible for the high densities of Harbor porpoises in these zones.

Abundance and Current Speed

Over all, porpoise density is affected by multiple variables. The finding that current speed was more important than current direction in determining porpoise abundance was although pronounced in zones 3 and 4 was not found in other zones. In zones without strong bathymetric complexity there was relatively low densities regardless of current speed. The Centennial survey results that porpoise density in zone 3 and 4 was highest during fast ebb and fast flood is consistent with previous studies (Vermiere 2010). However, these were not clear trends probably due to the coarse scale of this study. The relationship between abundance and current speed/direction was much clearer on the small boat surveys.

Depth Preference

The fact that the observed harbor porpoise preference for deep or shallow water varied with current speed/direction indicates that the bathymetry was not the only driving force. The porpoise's preference for shallow water during flooding tides was likely caused by the bathymetric effect explained above. In this case high turbulent mixing caused by the fast currents moving north from Cattle Pass into the ledge in zone 4 probably concentrated prey over the shallow shelf. Consistent with the high influx of copepods observed entering the channel during a flooding tide (Zamon 2001). The preference for deep water during ebbing tides is harder to explain. If porpoises were feeding during fast ebb, then these tides must have been able to aggregate pray from turbulent mixing. In this case the water was moving south over the ledge, so possibly it was pushing the accumulated prey out into the deeper water. Highest porpoise numbers during fast flood suggest that this was when the bathymetric effect was strongest. The similarity in porpoise density in shallow water during fast ebb, slow ebbs and slow floods was also interesting and suggests that there were similar intensities of turbulent mixing. Similar effects have been reported in bottlenose dolphins where hydrographic fronts create convergence zones for prey (Mendes 2002). In addition, underling bathymetry has also been found to increase predator aggressiveness and feeding in small cetaceans (Yen 2003, Hastie 2003)

Density Across Time

The finding that harbor porpoise density varied consistently at short time scales over the flooding tides demonstrated the importance of tides to feeding porpoises. Although abundance increased with increasing current speed the fact that density peeked before the maximum current velocity was reached and declines there after is interesting. The indication there was that the porpoises may have followed the tidal front up the channel. If the increasing current speed were increasing the bathymetric effect we would have instead expected porpoises to stay in this area and densities would have remained stable or increased. Another explanation may have been that the faster tide may result in decreased foraging efficiency due to the high amounts of energy required to capture prey (Mendes 2002). The observed absence of this increase on October 26th was difficult to interpret. The variation in harbor porpoise abundance over time agreed and disagreed from what was expected. The majority of small boat cruises agreed with the bathymetric effect, where density increased with increasing current speed (varying with direction). However there were a few days, which proved interesting. On October 26th, there was close to no change in density over time. This was strange because the two days prior showed the predicted trend. My observation that on October 29th higher porpoise abundance correlated with faster current speed, suggests that current speed may be more important to porpoises that current direction.

Implications and Suggestions

This study demonstrated clearly that harbor porpoise density varied considerably on short time and space scale. Thus scale should be considered in assessing populations. Accurate population estimates of harbor and dall's porpoises are essential for management and conservation of these species. Due to the variability of abundance in short temporal (tidal) and spatial scales local assessments are needed. Most past surveys have been administered on larger scales for example once a week or once a month that accuracy is a question. Given the apparent importance of short term variation, these surveys may not be representative of total populations. For example, a survey conducted during a tide preferred by porpoises may result in higher population estimates than a survey conducted on less ideal tides. Using fine scale surveys to calibrate current speed and direction preference might enable us to create a correction factor for a large scale survey. It would also be valuable to conduct a smaller temporal scale to study the effects of current speed and direction on dall's porpoises in a known feeding area to see if there is a similar response. Accurate knowledge of where, when, and how many porpoises are in an area may enhance efforts to reduce anthropogenic effects and mortality to these species, particularly the harbor porpoise.

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Tables and Figures

Table 1. Total number of Porpoises observed, average observed, standard deviation of average observed

Total area surveyed = 118.22 km^2

	Dall's	Harbor
Total	30	238
Average	0.16	1
Standard Deviation (+/-)	0.26	1.25

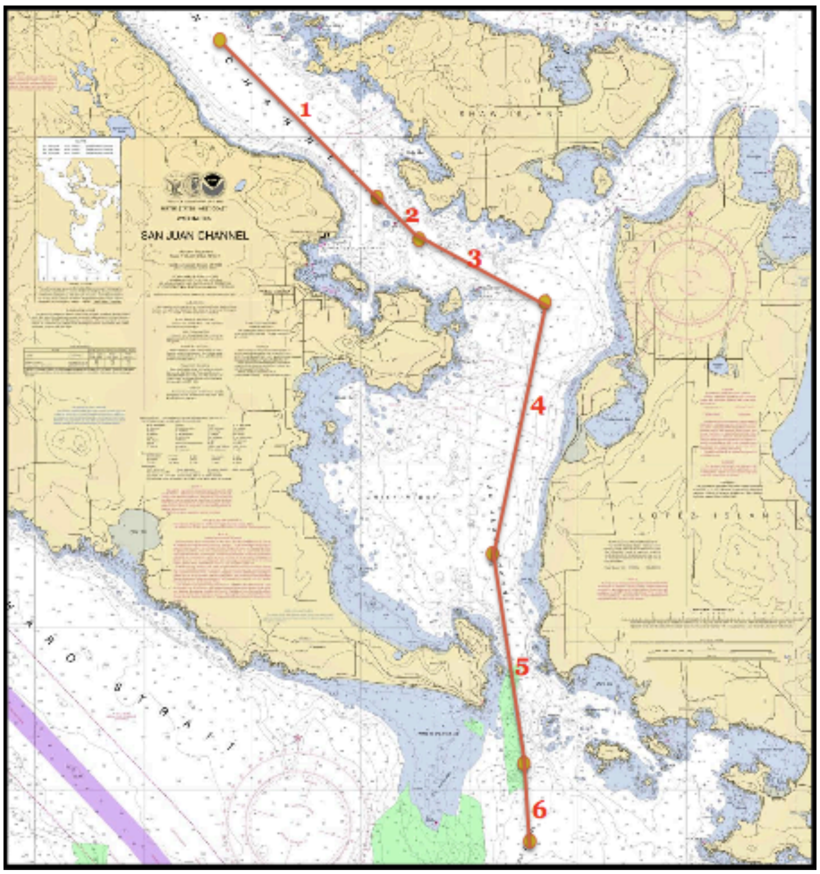

Figure 1. Zonal chart of the San Juan Channel (PEF), zone 1 is in the north and zone 6 is in the south

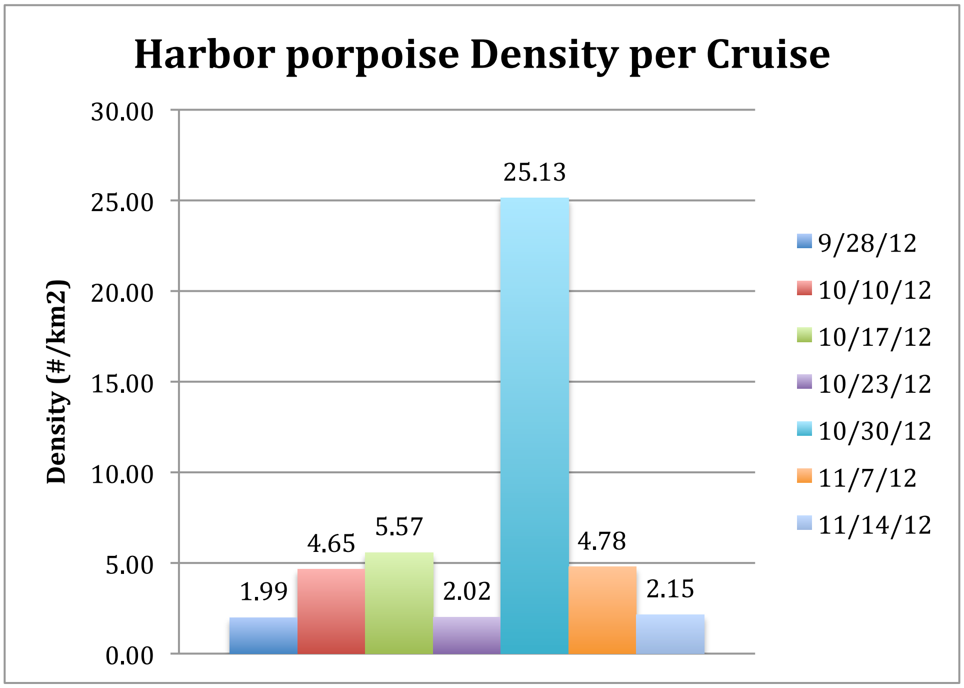

Figure 2. Abundance of Harbor porpoises per cruise Fall 2012

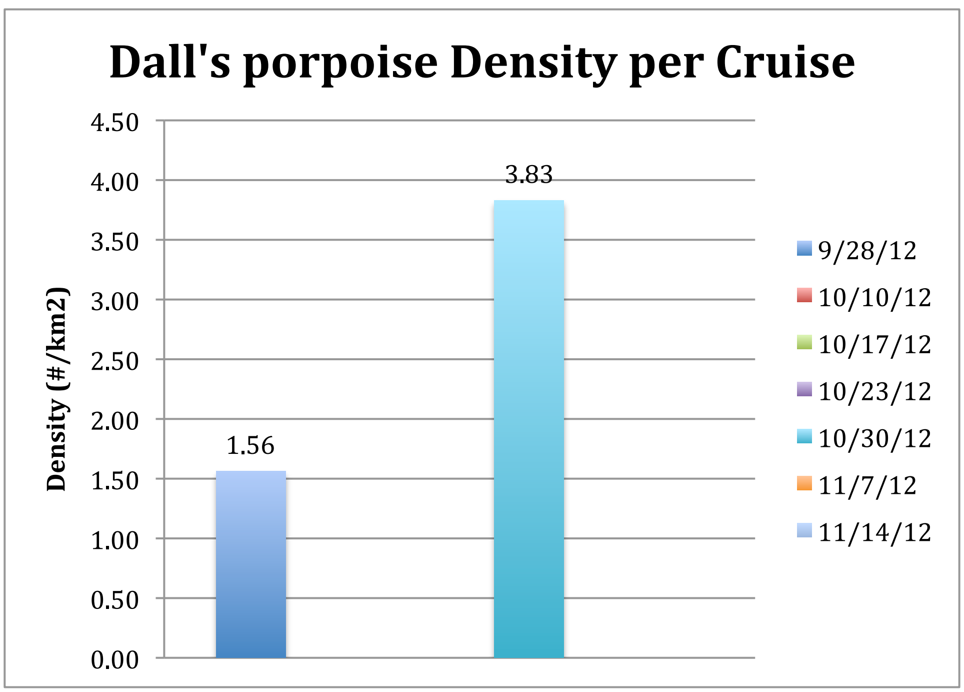

Figure 3. Abundance of Dall's porpoises per cruise Fall 2012

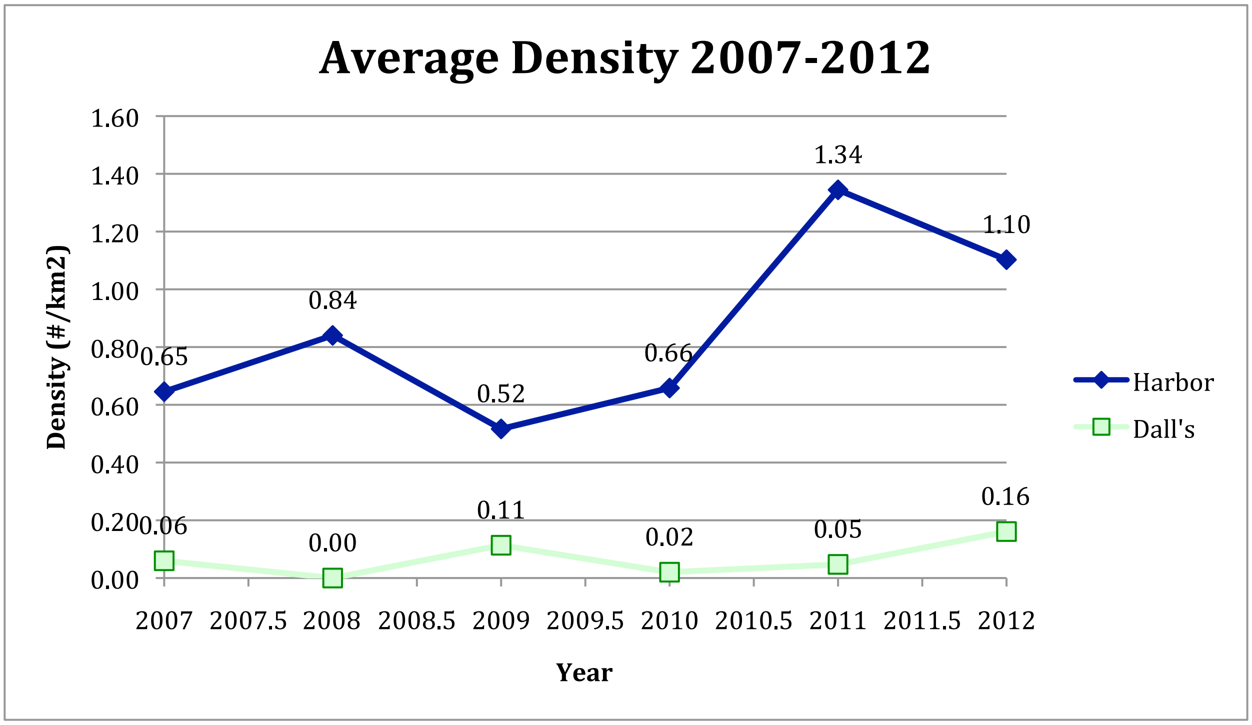

Figure 4. Average density of Harbor porpoises in San Juan Channel 2007-2012

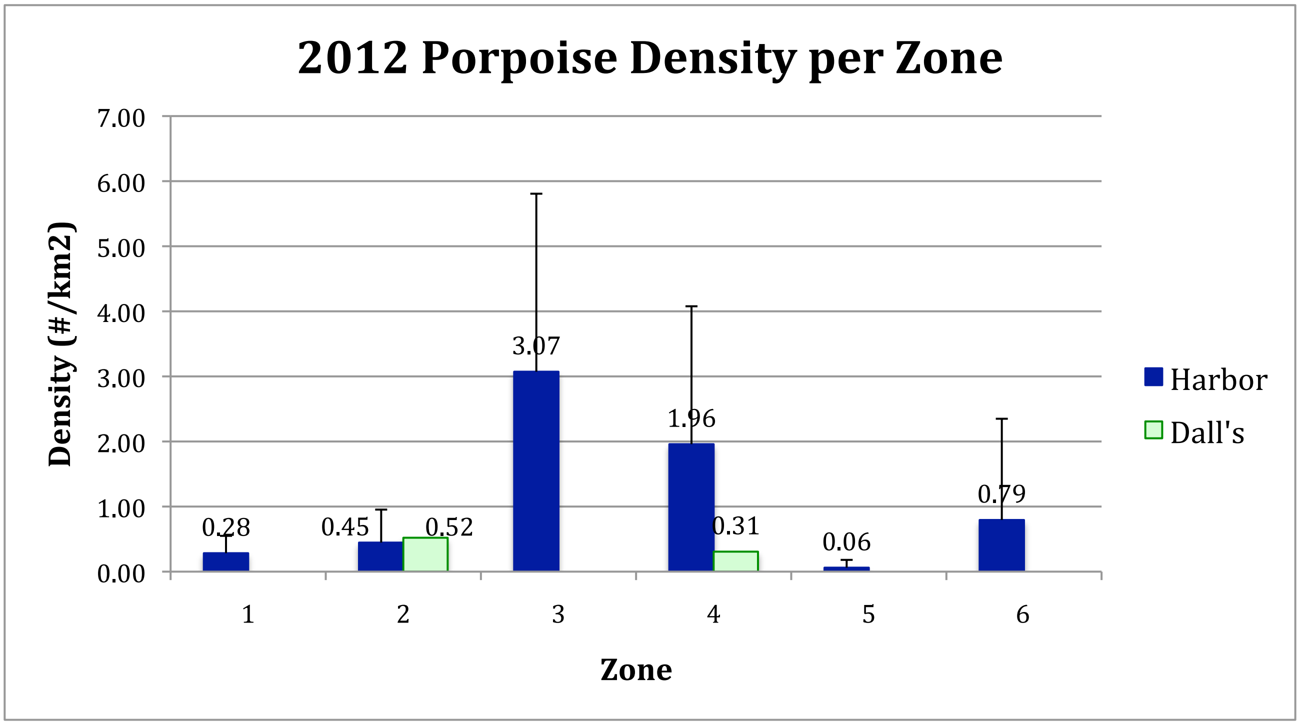

Figure 5. Harbor and Dall's porpoise density per zone for 2012 (standard deviation (+/-) from zone 1-6 for harbor porpoises are as follows: .26, .51, 2.73, 2.12, .12, 1.56)

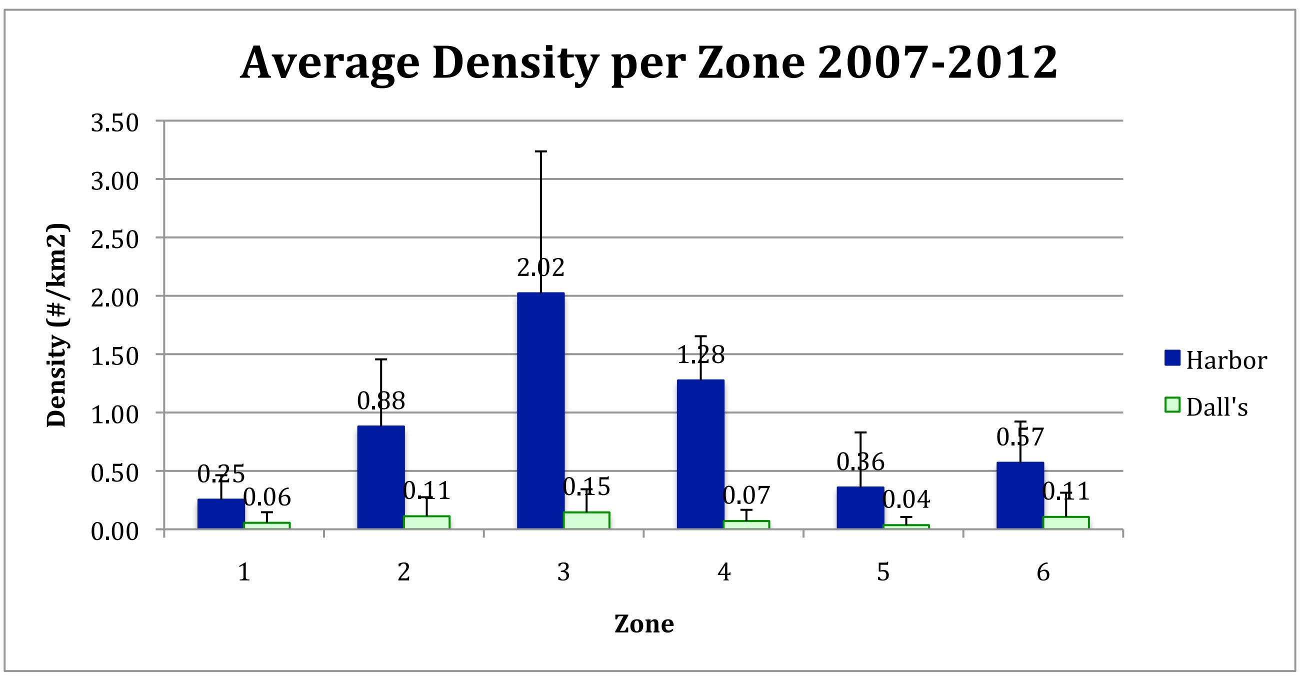

Figure 6. Average Density per zone for years 2007-2012 (the standard deviation (+/-) for zones 1-6 for harbor porpoises are as follows: .21, .57, 1.22, .38, .47, .35; the standard deviation (+/-) for zones 1-6 for Dall's porpoises are as follows: .09, .16, .20, .10, .07, .21)

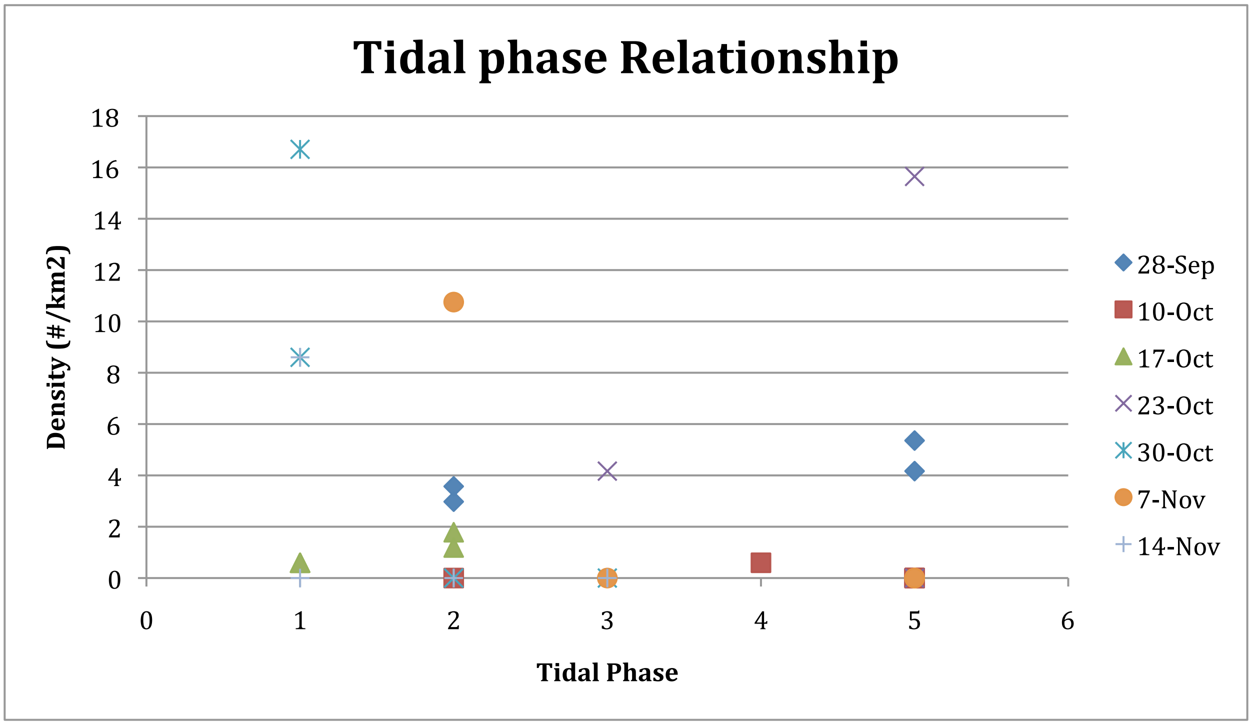

Figure 7. Density distribution relative to current speed and direction for zones 3 and 4 per cruise transect {FE = Fast Ebb, SE = Slow Ebb, S = Slack, SF = Slow Flood, FF = Fast Flood} where tidal phase corresponds to position on the tidal current speed chart

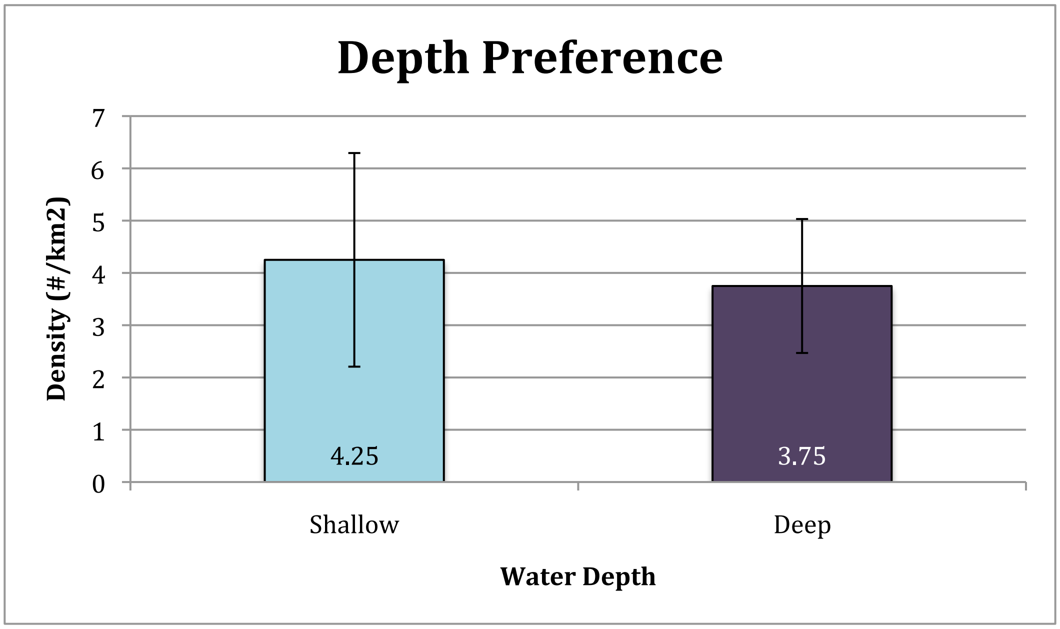

Figure 8. Depth preference for Harbor porpoises in Griffin Bay (shallow ≈ 80 m, deep ≈ 160 m) (standard deviation (+/-) for shallow is 2.04 and deep is 1.28)

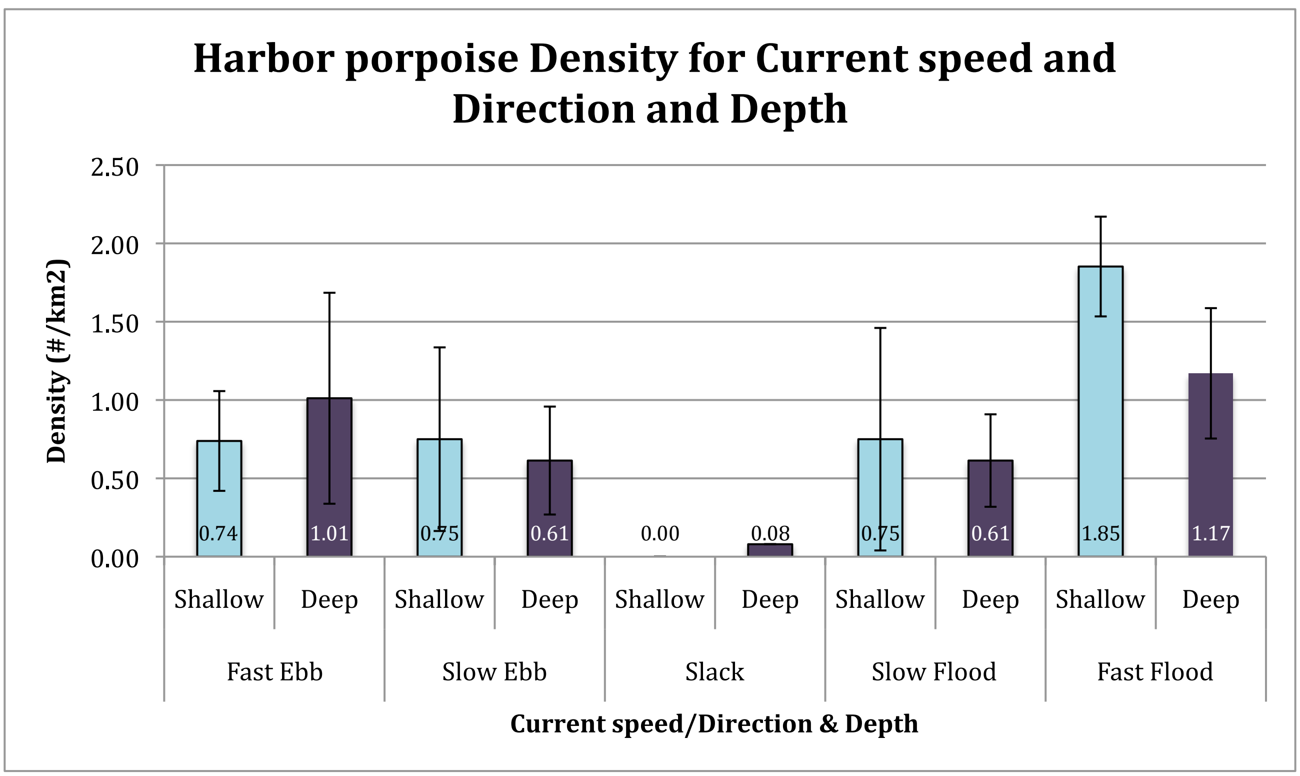

Figure 9. Depth preference for current speed and direction for Griffin Bay transects (shallow ≈ 80 m, deep ≈ 160 m) (standard deviation for current speed/direction and depth from fast ebb shallow to fast flood deep are as follows: .32, .67, .59, .34, n/a, n/a, .71, .30, .32, .42)

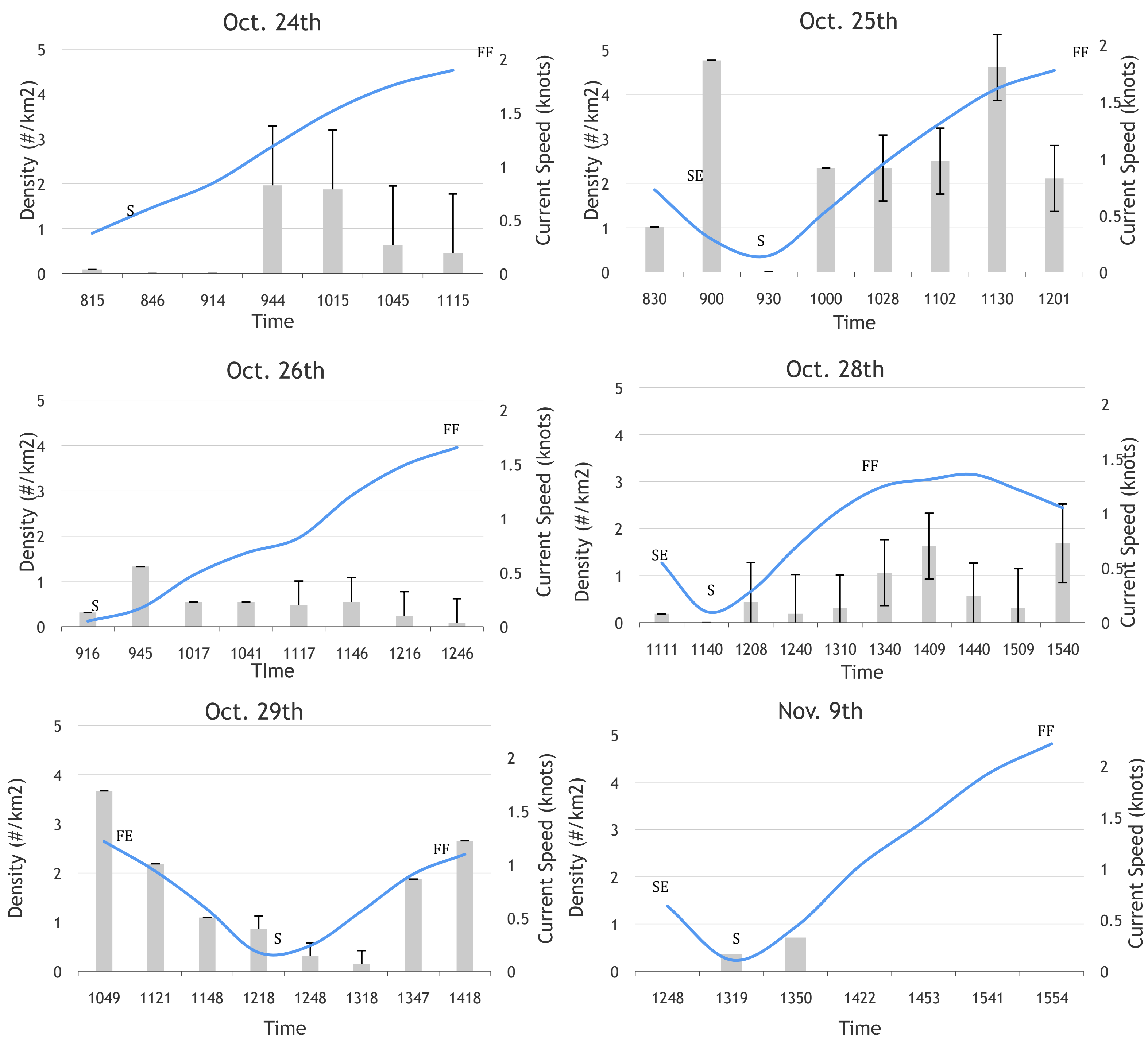

Figure 10. Harbor porpoise Distribution through Time (density represented by histogram, current speed represented by line). Letters on the current speed line symbolize the tidal phase (FE = Fast Ebb, SE = Slow Ebb, S = Slack, SF = Slow Flood, FF = Fast Flood) (standard deviation (+/-) for Oct. 24th is 1.33, Oct. 25th is .74, Oct. 26th is .54, Oct. 28th is .83 (1208 and 1240), .70 (1310-1440), and .83 (1509 and 1540), Oct 29th is .26, and Nov 9th is n/a)

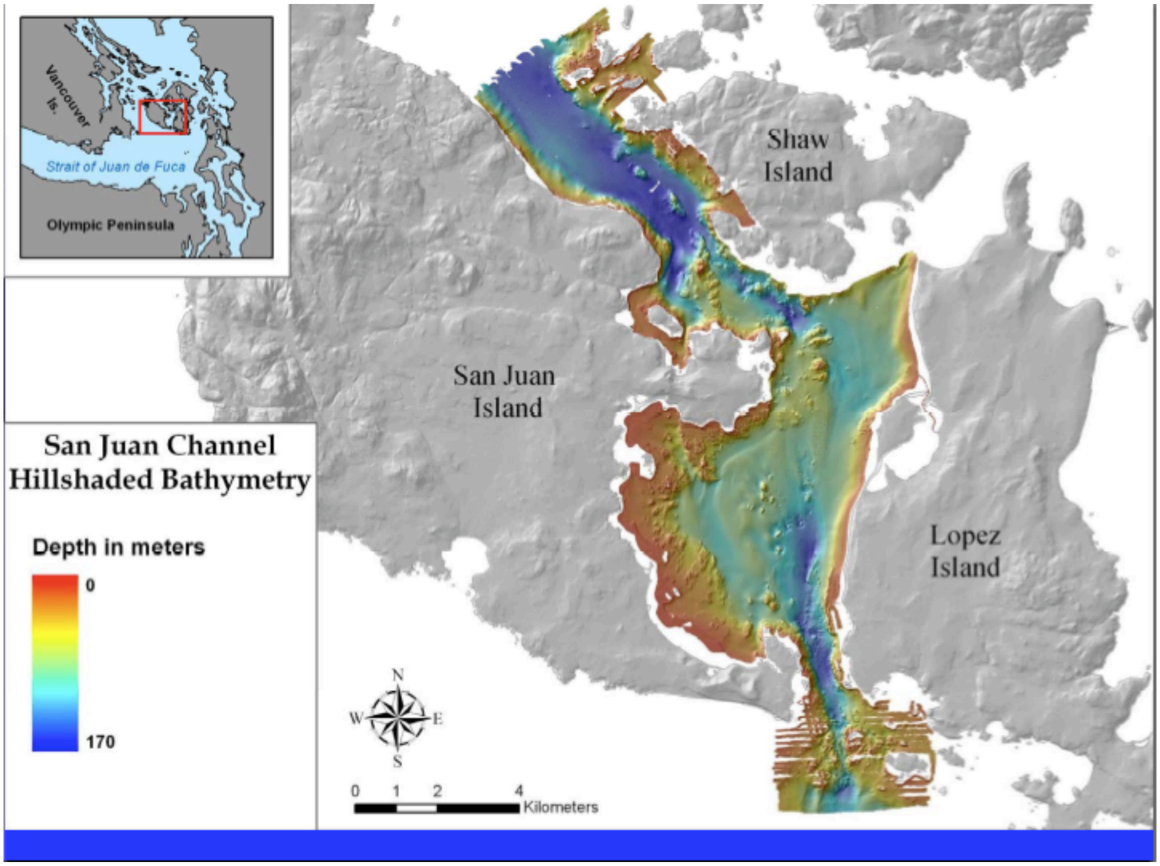

Figure 11. Bathymetric chart of the San Juan Channel (courtesy Gary Greene)

References

Bailey, Helen, Scott R. Benson, George L. Shillinger, Steven J. Bograd, Peter H. Dutton, Scott A. Eckert, Stephen J. Morreale, Frank V. Paladino, Tomoharu Eguchi, David G. Foley, Barbara A. Block, Rotney Piedra, Creusa Hitipeuw, Ricardo F. Tapilatu, and James R. Spotila. (2012). Identification of distinct movement patterns in Pacific leatherback turtle populations influenced by ocean conditions. Ecological Applications 22:735–747. http://dx.doi.org.offcampus.lib.washington.edu/10.1890/11-0633

Barlow, J. (1988). Harbour porpoise, *Phocoena phocoena*, abundance estimation for California, Oregon and Washington: I. Ship Surveys. Fish. Bull. **86**(3):417-432.

Calambokidis, John, Gretchen H. Steiger, David K. Ellifrit, Barry L. Troutman, and C. Edward Bowlby. "Distribution and Abundance of Humpback Whales (Megaptera Novaeangliae) and Other Marine Mammals off the Northern Washington Coast." *Fishery Bulletin* **102.4** (2004): 563-80. Web. 9 Nov. 2012.

Calambokidis, John, Jessie Huggins, Dyanna Laymourn, Steve Jeffreis, Joe Evenson, Bethany Diehl, Josh Oliver, and Brad Hanson. "Changes in Cetacean Occurrence in the Salish Sea: Anomalous Sightings in Southern Puget Sound." 2011 Salish Sea Ecosystem Conference. The Sheraton Wall Centre, Vancouver. 25 Oct. 2011. Lecture.

Friday, Nancy A., Janice Miles Waite, Alexandre N. Zerbini, and Sue E. Moore. "Cetacean Distribution and Abundance in Relationship to Oceanographic

Domains on the Eastern Bering Sea Shelf: 1999-2004." *Deep-Sea Research II* (2012): 260-72. *SciVerse ScienceDirect*. Web. 9 Nov. 2012.

Gaskin, D.E. (1992). Status of the Harbour porpoise, *Phocoena phocoena*, in Canada. Can. Field-Nat. **106**:36-54.

Hall, A., Ellis, G., and Trites, A.W. (2002). Harbor porpoise interactions with 2001 selective salmon fisheries in southern British Columbia and license holder reported small cetacean by-catch. Selective Salmon Fisheries Science Program, Fisheries and Oceans Canada, Victoria, B.C.

Hastie, G. D., B. Wilson, L. J. Wilson, K. M. Parsons, and P. M. Thompson. "Functional Mechanisms Underlying Cetacean Distribution Patterns: Hotspots for Bottlenose Dolphins Are Linked to Foraging." *Marine Biology* **144** (2004): 397-403. Web.

Iwamae, N., and T. Hibiya. "Numerical Study of Tide-indiced Mixing over Rough Bathymetry in the Abyssal Ocean." *Journal of Oceanography* **68.1** (2012): 195-203. *SpringerLink*. Web. 25 Nov. 2012.

Keple, Alison R. "Seasonal Abundance and Distribution of Marine Mammals in the Southern Strait of Georgia, British Columbia." Thesis. Malaspina University-College, 2002. Print.

Leatherwood, S., R.R. Reeves, W.F. Perrin & W.E. Evans. (1982). Whales, dolphins and porpoises of the eastern North Pacific and adjacent Arctic waters: A guide to their identification. NOAA Tech. Rep. NMFS Circular 444:1-245.

Mendes, Sonia, William Turrell, Thomas Lutkebohle, and Paul Thompson. "Influence of the Tidal Cycle and Tidal Intrusion Front on the Spatio-temporal

Distribution of Coastal Bottlenose Dolphins." *Marine Ecology-Progress Series* **239** (2002): 221-29. *Science Direct*. Web.

United States of America. National Oceanic and Atmospheric Administration. Office of Protected Resources. N.p., n.d. Web.

Osmek, S., J. Calambokidis, J. Laake, P. Gearin, R. DeLong, J.Scordino, S. Jeffries, and R. Brown. (1996). Assessment of the status of harbor porpoise (*Phocoena phocoena*) in Oregon and Washington waters. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-**76**, 46 p.

Osmek, S., J. Calambokidis & J.L. Laake. (1997). Distribution and habitat preferences of marine mammals in Washington and British Columbia inside waters. In: Calambokidis, J., S. Osmek & J.L. Laake. 1997. Aerial surveys for marine mammals in Washington and British Columbia inside waters. NOAA, NMML Final Report for Contract 52ABNF-6- 00092.

Pelagic Ecosystem Functions unpublished data. 2007-2011. Raw data. Friday Harbor Laboratories, Friday Harbor (locally archived).

Pereira, A. F., A. L. Belem, Belmiro M. Castro, and R. Geremias. "Tide-topography Interaction along the Eastern Brazilian Shelf." *Elsevier* **25** (2005): 1521-539. *Science Direct*. Web. 25 Nov. 2012.

Pike, G.C. & I.B. MacAskie.(1969). Marine mammals of British Columbia. Bull. Fish. Res. Bd. Canada. **171**. 55pp.

Raum-Suryan, K.L. & J.T. Harvey. (1998). Distribution and abundance of and habitat use by harbour porpoise, *Phocoena phocoena*, off the northern San Juan Islands, Washington. Fish. Bull. **96**:808-822.

Rothaus, Don P., Brent Vadopalas, and Carolyn S. Friedman. "Precipitous Declines in Pinto Abalone (Haliotis Kamtschatkana Kamtschatkana) Abundance in the San Juan Archipelago, Washington, USA, despite Statewide Fishery Closure." *Canadian Journal of Aquatic and Fisheries Sciences* **65** (2008): 2703-711. 2008. Web. 2 Dec. 2012.

United States of America. USDA Forest Service. *Marine Distribution, Abundance, and Habitats of Marbled Murrelets in British Columbia*. By Alan E. Berger. Vol. **152**. N.p.: n.p., 1995. Print.

Vermiere, L. (2010). Marine Mammels in San Juan Channel: Abundance, Distribution and Tidal Effects. Pelagic Ecosystem Function Apprenticeship, Friday Harbor Laboratories (locally archived).

Yen, Peggy P.W, William J. Sydeman, and K. David Hyrenback. "Marine Bird and Cetacean Associations with Bathymetric Habitats and Shallow-water Topographies: Implications for Trophic Transfer and Conservation." *Journal of Marine Systems* **50** (2004): 79-99. *Science Direct*. Web.

Zamon, Jeannette E. "Mixed Species Aggregations Feeding upon Herring and Sandlance Schools in a Nearshore Archipelago Depend on Flooding Tidal Currents." *Marine Ecology-Progress Series* **261** (2003): 243-55. Web.

Zamon, Jeannette E. "Seal Predation on Salmon and Forage Fish Schools as a Function of Tidal Currents in the San Juan Islands, Washington, USA." *Fisheries Oceanography* **10.4** (n.d.): 353-66. *Fisheries Oceanography* (2001). Web. 1 Dec. 2012.