San Juan Channel Seabird Abundance Patterns of Fall
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Pelagic Ecosystem Apprenticeship 2013

Abstract
Seabirds are an important component of many marine ecosystems, but are in decline in many parts of the world. While some studies have shown that Salish Sea seabirds are declining, PEF has found no evidence of this decline. I attempted to characterize the seabird community of fall 2013, as well as try to establish whether or not tidal influences have been biasing our data collection. I used strip transect survey methods to analyze the seabird community of 2013 and compare it to previous years, and looked at three tidal metrics (tidal current speed, tidal current direction, and maximum tidal exchange) to determine whether or not PEF has a sampling bias in regards to tides. The abundance of seabirds in 2013 was relatively low, but not anomalously so, and the community composition for this year is consistent with that of past years. Furthermore, analyses of the tidal metrics yielded no evidence of sampling bias. Therefore, it is likely that the interannual patterns observed by PEF in the past are real and are possibly due to global climate patterns.

Introduction

Seabirds are vital components to most marine ecosystems and are valuable in determining ecosystem health (Bower, 2009) because they are highly visible and relatively easy to observe and identify. The Salish Sea is established as an important nesting and overwintering site for marine birds, (Gaydos, 2007). Relatively few surveys of marine bird populations were conducted in this area before 1970, but more recent studies have shown that seabird populations in the Salish Sea have been declining for the last 25 years due to various anthropogenic effects (Bower, 2009). Surveys conducted by past Pelagic Ecosystem Function (PEF) Apprentices, however, have found no decline in autumn seabird populations over the last eight years (Albrecht, 2012).

There are several possible explanations for this discrepancy. It might reflect seasonal and regional differences in avifauna. PEF is the only study done in the San Juan Channel and the only one conducted during the fall. It could also reflect a shifting baseline; that is, population declines occurred prior to the start of the PEF studies. However, it is also possible that these coarse-scale weekly surveys are not adequately assessing variability at all scales. For example, tidal currents in particular have been shown to greatly impact local bird abundance at a small temporal scale (Eisenlord, 2012). Since the PEF survey technique is not randomized in respect to tidal conditions, it is possible that tides are sampled differently from one year to the next, thus potentially creating a "tidal bias." This bias could account for the interannual differences in seabird population trends in the San Juan Islands.

My goals for this study were, therefore:

1.To assess abundance, community composition, and distribution of seabirds in fall of2013

2. To compare 2013 to previous years

3. To determine whether or not the interannual pattern reflects a tidal bias.

Methods

We conducted bird surveys in San Juan Channel on seven cruise dates from 26 September to 13 November, 2013, aboard the *R/V Centennial,* a 58-foot research vessel. The *Centennial* maintained an average speed of approximately eight knots. These surveys employed the strip transect technique. The 21.5 km transect started near Yellow Island (48.5667ºN, 123.0125ºW) and ended south of Cattle Point in the Strait of

Juan de Fuca (48.4269ºN and 122.9452ºW). The transect was divided into six geographic zones based loosely on bathymetric features (Figure 1). We conducted two transects per cruise date. Observers positioned on the bow recorded all birds within 200m on both sides of the vessel (400m total corridor width). Birds were identified to species, except for the Brandt's and Pelagic cormorants, which I grouped together for analyses due to identification error. Birds that could not be identified to species were identified to the lowest possible taxon.

Bird data were compiled and analyzed using Microsoft Excel. Abundance was measured as density, calculated using the formula *density = #birds/transect area* (km^2). Error bars indicate a 95% confidence interval.

To determine whether or not PEF survey effort was consistent among years, I characterized each survey for three tidal traits: Tidal current speed, tidal current direction, and maximum tidal exchange. I determined these at the midpoint (time) for each transect. Tidal current speed and direction values were based on the Turn Rock Tidal Station, which is the closest to the midpoint of the transect. Maximum tidal exchange was calculated by determining the largest exchange in the 24 hours prior to each *Centennial* trip based on tidal data from NOAA's Friday Harbor tidal station. Therefore, tidal exchange was calculated for each cruise date and not for each transect.

Results

In 2013, PEF surveyed a total of 111.8 km^2 and counted 9,659 individual birds for a total season density of 86.39 ± 26.3 birds per km^2. Six families and 33 species were present this year. The families Laridae (gulls) and Alcidae (murres and auklets) were the two most common families, together making up 81 percent of all birds seen. The family Phalacrocoracidae (cormorants) accounted for 11 percent of the total, while the families Anatidae (ducks and geese), Podicipedidae (grebes), and Gaviidae (loons) collectively accounted for the last eight percent (Figure 2).

Gulls and Alcids: Species Density and Within-Season Variation

Gulls were the most common family in 2013 (40.15± 16.47). The Glaucous-winged and Bonaparte's gull were the two most abundant gulls this fall, each with a mean season density of above 10. Mew Gulls were also abundant (7.35 ± 6.10), while Heermann's and California gulls both had total densities of under 5 (Figure 3).

Gull abundance was variable over the season, but individual patterns were species-specific (Figure 4). Glaucous-winged Gulls overall displayed a slight increase throughout the season. California and Heermann's gulls showed a decrease over the season and were both completely absent from all surveys by late October. Bonaparte's gulls did not show up on surveys until mid-October and thereafter increased dramatically. Mew Gulls started to increase in early October, but their numbers did not peak until November.

Alcids were the second most abundant family of 2013 (29.99 ± 10.5). Common Murres dominated the counts at a density of 28.56 ± 13.33 and accounted for over three-quarters of all alcids seen (Figure 5). All other alcids had total season abundances of less than 5.

Like the gulls, alcids were highly variable over the season but displayed species-specific abundance patterns (Figure 6). Common Murres and Marbled Murrelets did not display a net increase or decrease. Rhinoceros Auklets decreased slightly over the season, while Ancient Murrelets showed a dramatic increase at the beginning of November.

Gull and Alcid Distribution

The gull family displayed three distinct distribution patterns within the San Juan Channel: an increase in abundance to the south, an increase in abundance to the north, and no change in abundance across all six zones. Glaucous-winged and Heermann's Gulls were more abundant in the south of the transect (Zones 5 and 6), while Bonaparte's Gulls were most abundant in Zones 1 through 4, and almost completely absent from 5 and 6. Mew and California Gulls were equally abundant in all zones (Figure 7).

Alcids were either most common in the south or in the middle of the transect (Figure 8). Common Murres were most abundant in the south, reaching a mean density of over 100 in Zone 6. Rhinoceros Auklets and Marbled Murrelets displayed the highest abundances around Zone 4. Pigeon Guillemot and Ancient Murrelet numbers were too low to determine distribution patterns.

Community Composition

The ten most abundant species of 2013 included four gulls, three alcids, one duck, one loon, and the two cormorants (Table 1). The Common Murre was the most abundant species, with a mean season density of 28.56 ± 13.3. The Glaucous-winged, Bonaparte’s, and Mew gulls all had mean season densities of above 7, and all others were less than 5.

Tidal Analyses

Seabirds showed significant responses to some tidal variables but not others. During fall 2013, both total Common Murre abundance and total bird (all species combined) abundance showed no significant relationship with tidal current speed (Figure 9).

Common Murres showed a significant relationship with tidal current direction in 2013 (Figure 10) (1-way ANOVA, $F_{(1, 13)}$=8.8, p=0.012), with higher numbers during flood tides. The trend was only found in one other year (2010), and was not found for the combined 2007 to 2013 data set (Figure 11). Total seabird abundance did not vary significantly with tidal direction in 2013 (1-way ANOVA, $F_{(1,13)}$=2.65 p=0.13).

For most years, similar numbers of surveys were conducted on ebb and flood tides (Table 2). Even in 2007 and 2008, when twice as many surveys were done on ebb tides than on flood tides, there was no significant relationship between murre abundance and tidal direction. Of note, however, is that murres were the least abundant during these two years.

For 2013, tidal exchange was not found to significantly affect seabird abundance (1-way ANOVA**,** $F_{(1, 7)=}$45.9, p=0.11) or Common Murres (1-way ANOVA, $F_{(1, 7)}$ = 2.54, p=0.44) (Figure 12). 2012 was the only year in which more samples were taken on high exchange days than low, with a high exchange to low exchange ratio of 6:2. 2011 and 2013 had even numbers of samples on high and low exchanges (Table 3).

Discussion

The total season abundance for 2013 was the lowest it has been for the last four years, but is still within range of all the years of PEF study (Figure 13). Therefore, PEF has observed no net increase or decrease in seabird abundance for the last eight years. Similarly, PEF has not seen any overall change in community composition (Table 4). Glaucous-winged Gulls and Common Murres have consistently been the top two species, and many of the same species are highly abundant every single year.

Almost all the within-season temporal patterns can be explained by migration (Sibley, 2000, Albrecht, 2012). The California and Heermann's Gulls, which were almost completely absent from surveys starting in mid to late October, summer in the San Juan Islands and fly south for the winter. Meanwhile, Bonaparte's Gulls migrate into the sheltered inland waters of the San Juan Channel from breeding grounds up north. Even among the residential seabirds, season variation was observed. Common Murres, breed on the outer coast and migrate into the sheltered waters for the winter, while Rhinoceros Auklets do the opposite and tend to leave for the outer coast in the fall (Lewis & Sharpe, 1987). Marbled Murrelets and Glaucous-winged Gulls are both residents, though individuals migrating through the area could account for increased numbers on certain days. Mew Gulls and Ancient Murrelets are winter residents and so arrive in the fall, but this year Ancient Murrelets arrived late and in very low numbers, suggesting that the bulk of their migration did not occur during this study.

Overall, seabird population distribution patterns varied in relation to tidal features. In general, birds were either found in the sheltered, inland waters of the channel or in the more turbulent Strait waters outside Cattle Pass. Cattle Pass is a very tidally active area, as large amounts of water are forced through the narrow pass during tidal exchanges. These kinds of high current areas have been shown to attract many kinds of seabirds (Zamon, 2003). Pelagic species, such as the Common Murre, Glaucous-winged Gull, and Mew Gull were all more abundant in these areas. Bonaparte's Gulls, however, are very small gulls that prefer the sheltered inland waters of the Channel as opposed to the more exposed waters of the Strait (Burger & Gochfeld, 2002). Thus, they were almost never observed in Zones 5 and 6, which lie outside Cattle Pass.

The lack of a relationship between tidal current speed and seabird abundance is unexpected. Tidal current speed has been shown to increase mixing and attract certain species of seabirds to feed (Holm 2002, Zamon 2003). The higher turbulence caused by faster currents brings plankton and fish closer to the surface where birds can reach them; therefore I would expect to see some evidence that more seabirds are present when tides are moving faster.

My finding of higher abundance on flooding tides is consistent with other studies conducted in this region. Flooding tides bring oceanic water from the Strait of Juan de Fuca into the San Juan Channel, while ebbing tides drag fresh water from the Fraser River in from the north (Gould 2013, Thompson 2013). Therefore, flooding tides force plankton, forage fish, and other food sources from the open ocean and thus can attract seabirds (Zamon, 2003).

Although there was no clear relationship, tidal exchange could affect seabird abundance in the following ways. A large tidal exchange prior to the survey has been shown to positively correlate with seabird abundance (Bliss, 2013, Schlatter, 2013). If the tidal exchange prior to the sampling effort is high, the water will be denser, colder, and contain greater numbers of plankton and forage fish. These conditions are ideal for seabirds.

Critique of Methods

One difficulty with this type of analyses is that it is difficult to characterize an entire transect as one value. Our transects are long and cover a large portion of the tidal cycle, and I chose to use the midpoints in both time and distance to try and determine whether each transect was a flood or ebb tide. This methodology is ignoring a lot of the smaller-scale variation that is certainly occurring during the course of the transect. However, because population estimates by necessity must use coarse-scale sampling techniques, any investigation of the soundness of those techniques must also be conducted on a coarser scale.

Because it is known that tides play an important role in where an when birds appear, it is important that they be taken into consideration. If PEF has been sampling tides differently on different years, that difference could account for some of the interannual patterns in seabird abundance. A clear, unbiased data set is necessary for long-term population estimates. Therefore, I have analyzed our long-term data in regards to tidal current speed, tidal current direction, and maximum exchange. Of these three, only tidal current was a potential sources of bias.

Although tidal direction played an important role in Common Murre abundance in 2010 and 2013, overall this tidal feature does not appear to be biasing the larger PEF data set. On neither of those years did PEF sample an uneven amount of flooding and ebbing tides. In fact, the only two years with a possible sampling bias were 2007 and 2008, during which tidal direction did not prove to be a source of bias.

Causes of Interannual Differences

If the interannual differences are not caused by a sampling bias, than it is likely that local conditions are playing a large role in where and when seabirds appear. Table 5 lists the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), average local sea surface temperatures, and mean bird density since 2007. Although there is no clear trend linking years of higher bird abundances to any one of these conditions, it appears that a combination of certain ENSO and PDO conditions might be influencing bird abundance. During yeas that are display both La Niña conditions and cool PDO, there tend to be higher numbers of seabirds. For example, 2010 was a year high in birds; it was also a La Niña year and a cooler PDO.

Although it is not perfectly defined, this trend seems to be present in 2010 through 2012. 2013 is an El Niño neutral year and a cool PDO, and as a result the surface waters are not as cool as they have been over the last three years. This could explain why 2013 was much less seabird abundant than the 2010 through 2012. Similarly, 2007 through 2009 do not display this La Niña and cool PDO combination, and were all years of lower seabird density.

The differences in interannual seabird abundance seem to be more closely linked to global climate patterns than to any sampling bias on the part of PEF. Although it is possible there are other factors influencing when and where seabirds are found, tidal conditions do not seem to be playing a large role. At the very least, PEF has not displayed much sampling bias in relation to these factors over the last eight years. This lack of bias leads me to conclude that the PEF methodology is sound and that no sampling bias is skewing the data. The fall populations of San Juan Channel seabirds have displayed no decline over the last decade. In addition, the status of species of local concern seems to be stable. However, further monitoring and a deeper analyses of tidal factors is necessary for this area.

Acknowledgements
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Tables and Figures

Table 1: Top ten most abundant seabirds during fall of 2013 in the San Juan Channel.

Species	Density (± 95% Confidence)
Common Murre	28.56 ± 13.3
Glaucous-winged Gull	13.64 ± 7.1
Bonaparte's Gull	12.83 ± 10.1
Mew Gull	7.35 ± 6.1
Pacific Loon	3.87 ± 2.0
Brandt's/Pelagic Cormorant	3.27 ± 1.1
Heermann's Gull	3.02 ± 3.2
Rhinoceros Auklet	3.01 ± 1.7
Marbled Murrelet	2.3 ± 0.8
Surf Scoter	1.42 ± 0.9

Table 2: Interannual patterns in tidal current direction and Common Murre abundance 2007-2013. Flood:Ebb represents the number of surveys conducted on flood versus ebb tides that year.

Year	Flood:Ebb	Common Murre Density	F-value	P-value
2007	4 flood, 8 ebb	9.53	0.98	0.34
2008	5 flood, 10 ebb	11.3	0.0007	0.93
2009	7 flood, 9 ebb	16.57	0.93	0.35
2010	7 flood, 8 ebb	47.71	12.46	0.004
2011	5 flood, 7 ebb	22.87	0.17	0.69
2012	5 flood, 9 ebb	65.99	0.15	0.71
2013	8 flood, 5 ebb	28.56	8.8	0.012

Table 3: Interannual patterns in tidal exchange and total seabird abudnace. High to low exchange ratio reflects the number of cruises done on days with high versus low exchanges prior

Year	High Exchange:Low Exchange	Bird Density (± 95% CI)
2011	9 High, 14 Low	121 ± 23
2012	11 High, 17 Low	168 ± 8.9
2013	10 High, 18 Low	86 ± 25.9

Table 4: Top ten most abundant species 2008-2013. Blue=species consistenetly in top 2; Red=highly volatile species; Green=constant species; Grey=anomalous species.

	2008	2009	2010	2011	2012	2013
1	Glaucous-winged Gull	Glaucous-winged Gull	Common Murre	Common Murre	Common Murre	Common Murre
2	Common Murre	Common Murre	Rhinoceros Auklet	Glaucous-winged Gull	Glaucous-winged Gull	Glaucous-winged Gull
3	Bonaparte's Gull	Mew Gull	Glaucous-winged Gull	Bonaparte's Gull	Bonaparte's Gull	Bonaparte's Gull
4	Ancient Murrelet	Brandt's Cormorant	Heermann's Gull	Ancient Murrelet	Rhinoceros Auklet	Mew Gull
5	Mew Gull	Pacific Loon	Mew Gull	Pacific Loon	Heermann's Gull	Pacific Loon
6	Rhinoceros Auklet	Bonaparte's Gull	Brandt's Cormorant	Rhinoceros Auklet	Mew Gull	Brandt's/ Pelagic Cormorant
7	Pacific Loon	Marbled Murrelet	Ancient Murrelet	Brandt's Cormorant	Ancient Murrelet	Heermann's Gull
8	Brandt's Cormorant	Heermann's Gull	Bonaparte's Gull	Marbled Murrelet	Pacific Loon	Rhinoceros Auklet
9	Heermann's Gull	Ancient Murrelet	Pacific Loon	Mew Gull	Marbled Murrelet	Marbled Murrelet
10	Surf Scoter	Surf Scoter	Surf Scoter	Heermann's Gull	California Gull	Surf Scoter

Table 5: Global climate patterns 2007-2013. PDO=Pacific Decadal Oscillation; ENSO= El Niño Southern Oscillation; Local SST= local sea surface temperatures.

	2007	2008	2009	2010	2011	2012	2013
PDO	Neutral	Cool	Neutral	Cool	Cool	Cool	Cool
ENSO	La Niña	Neutral	El Niño	La Niña	La Niña	Weak El Niño	Neutral
Local SST	Cooler	Moderate	Warmer	Cooler	Cooler	Cooler	Mod/warmer
Birds	Low	Low	Low	High	Medium	High	Low

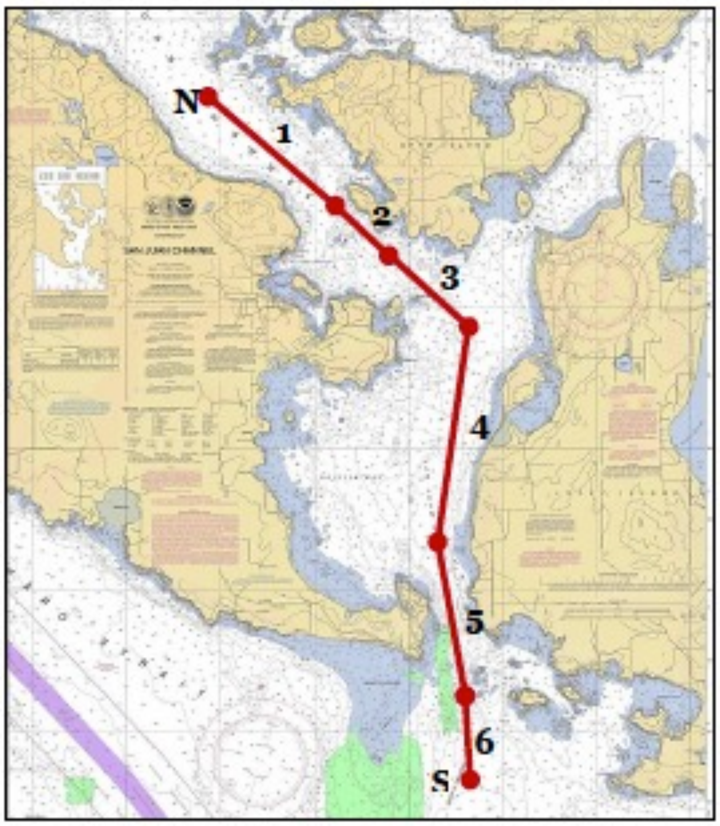


Figure 1: PEF seabird transect route through San Juan Channel

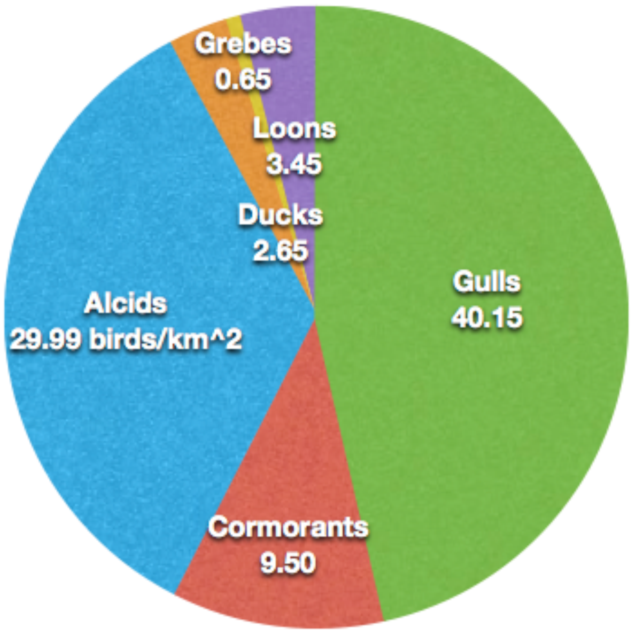


Figure 2: San Juan Channel seabird community Fall 2013. Numbers represent density is in birds per km^2.

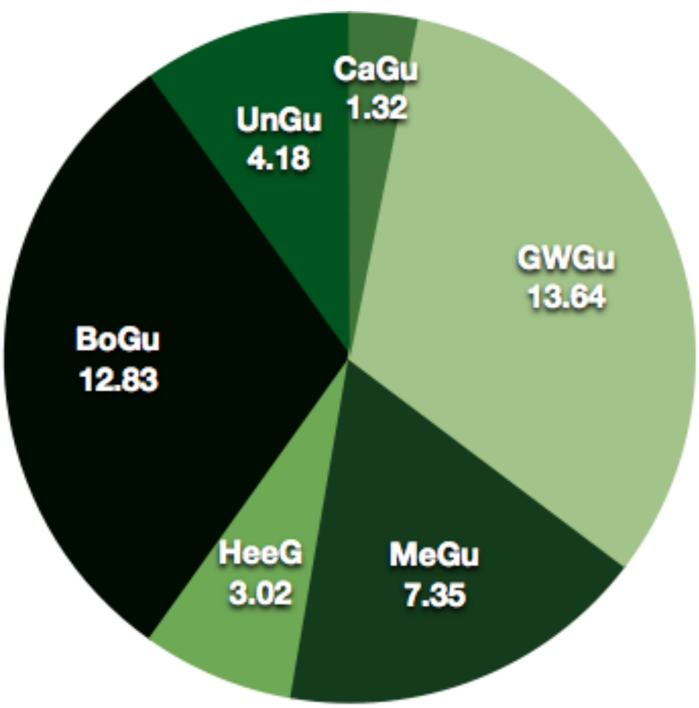


Figure 3: Laridae (gull) community of San Juan Channel Fall 2013. Numbers represent density is in birds per km^2.

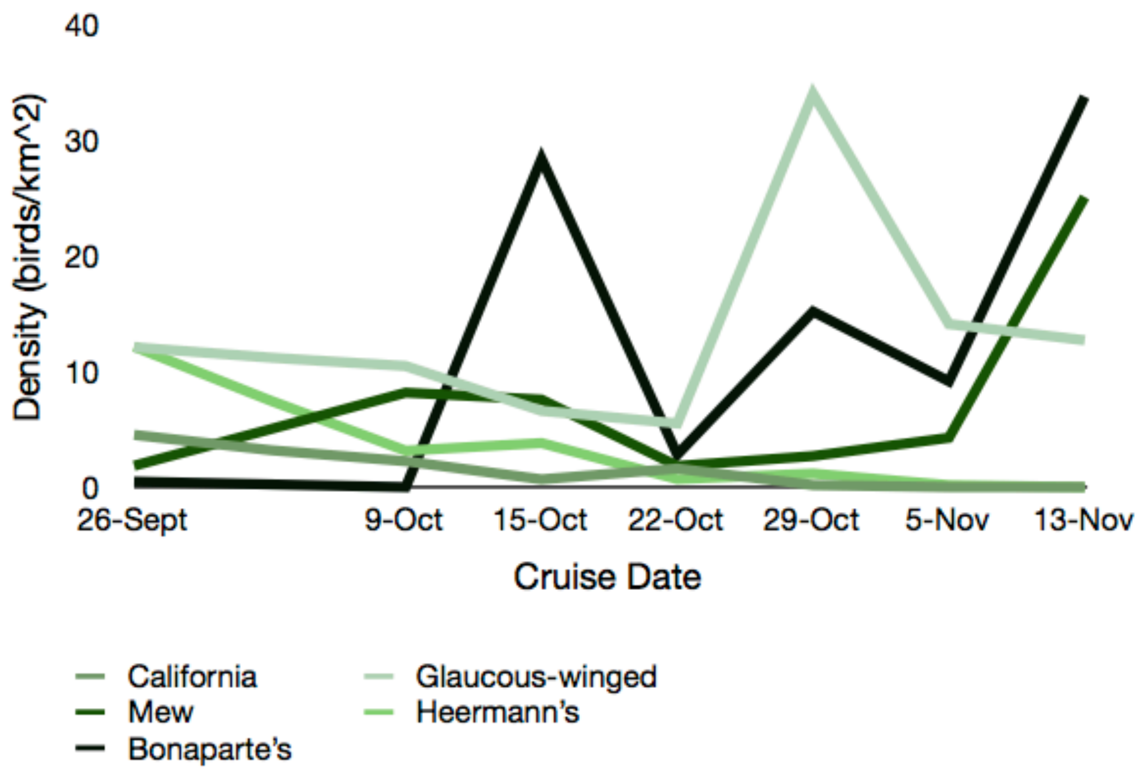


Figure 4: Within-season variation of the five species of gull in the San Juan Channel.

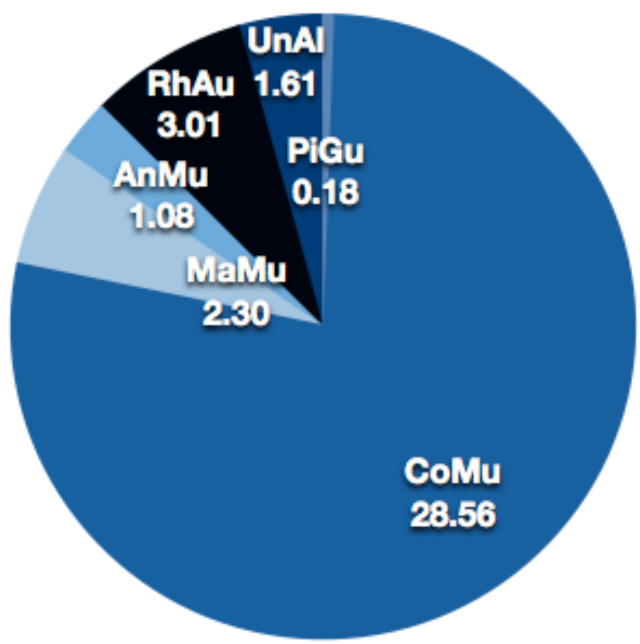


Figure 5: Alcid community of the San Juan Channel Fall 2013. Numbers represent density is in birds per km^2.

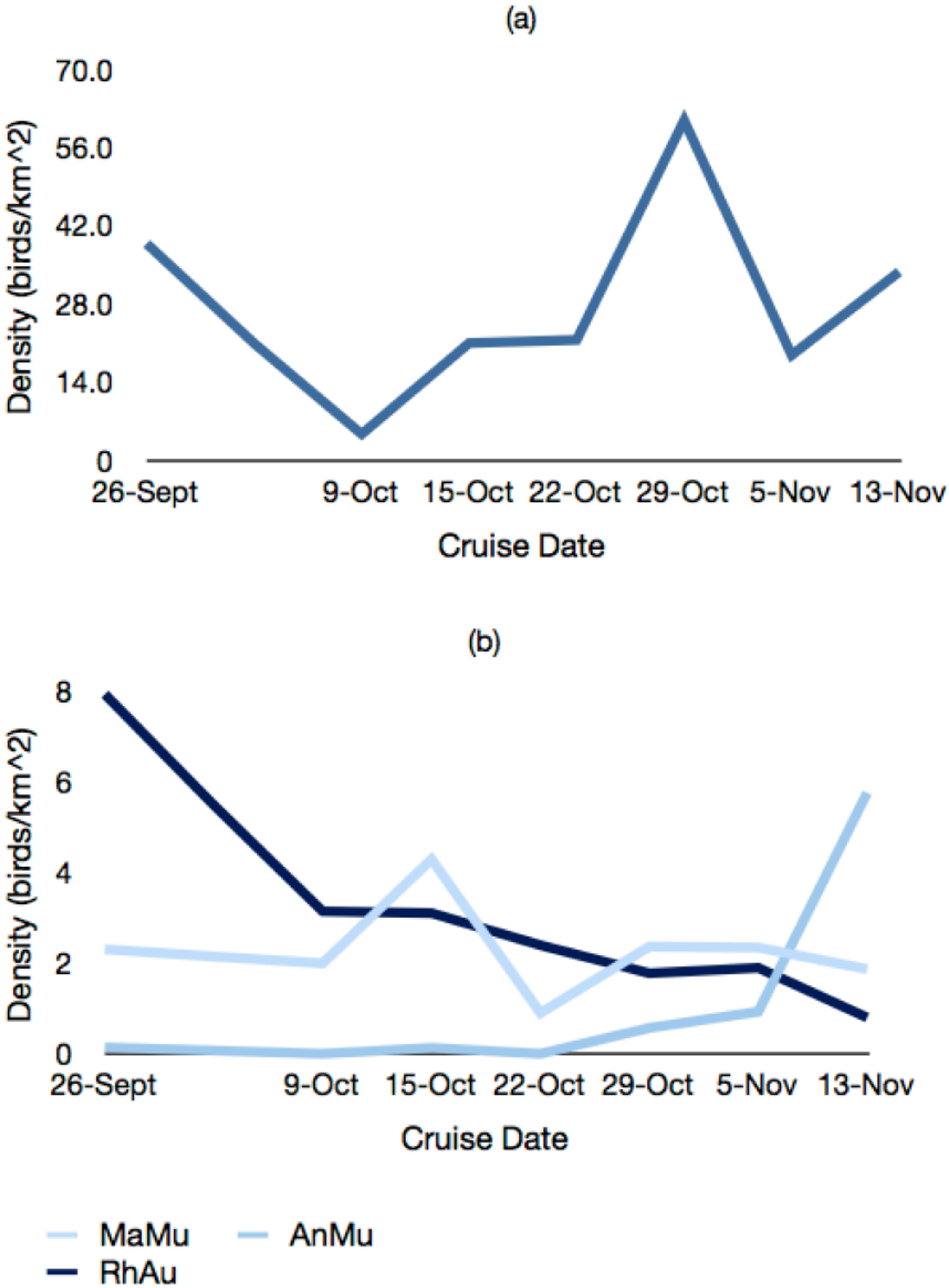


Figure 6: Within-season variation of a) Common Murres, and b) all other alcids. Common Murres are separated due to their much higher densities.

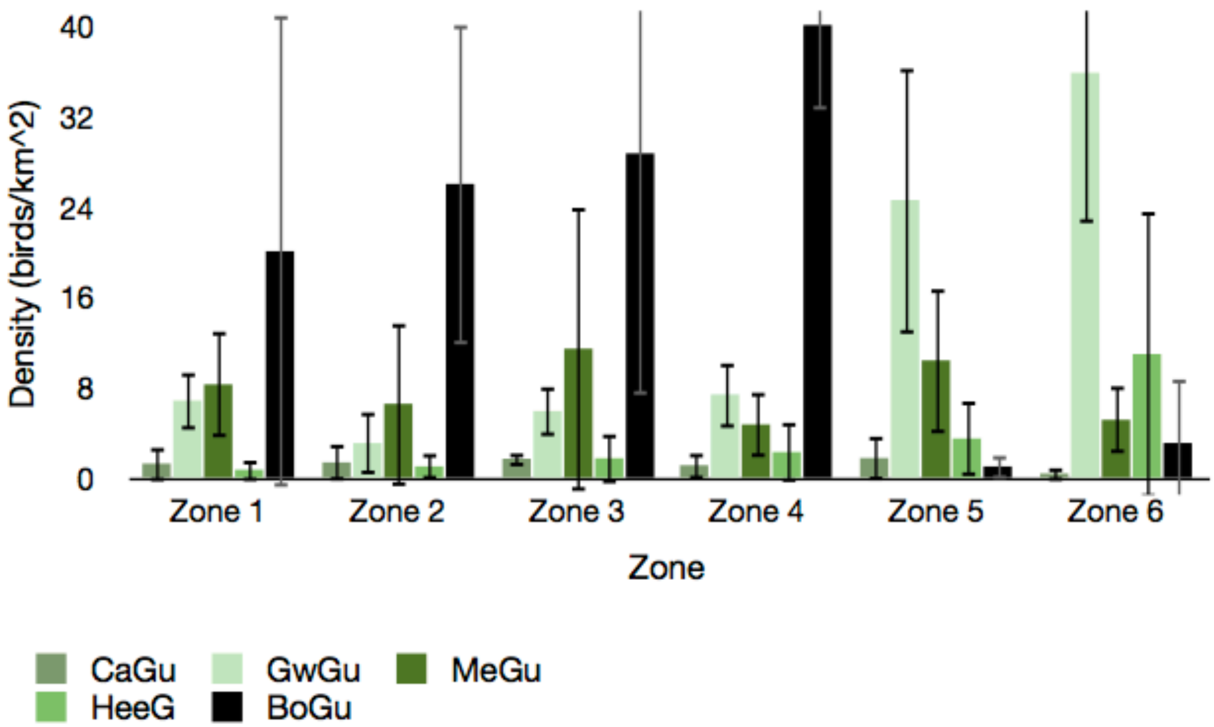


Figure 7: Spatial Distribution of gulls in the San Juan Channel Fall 2013. Error bars represent a 95% confidence interval.

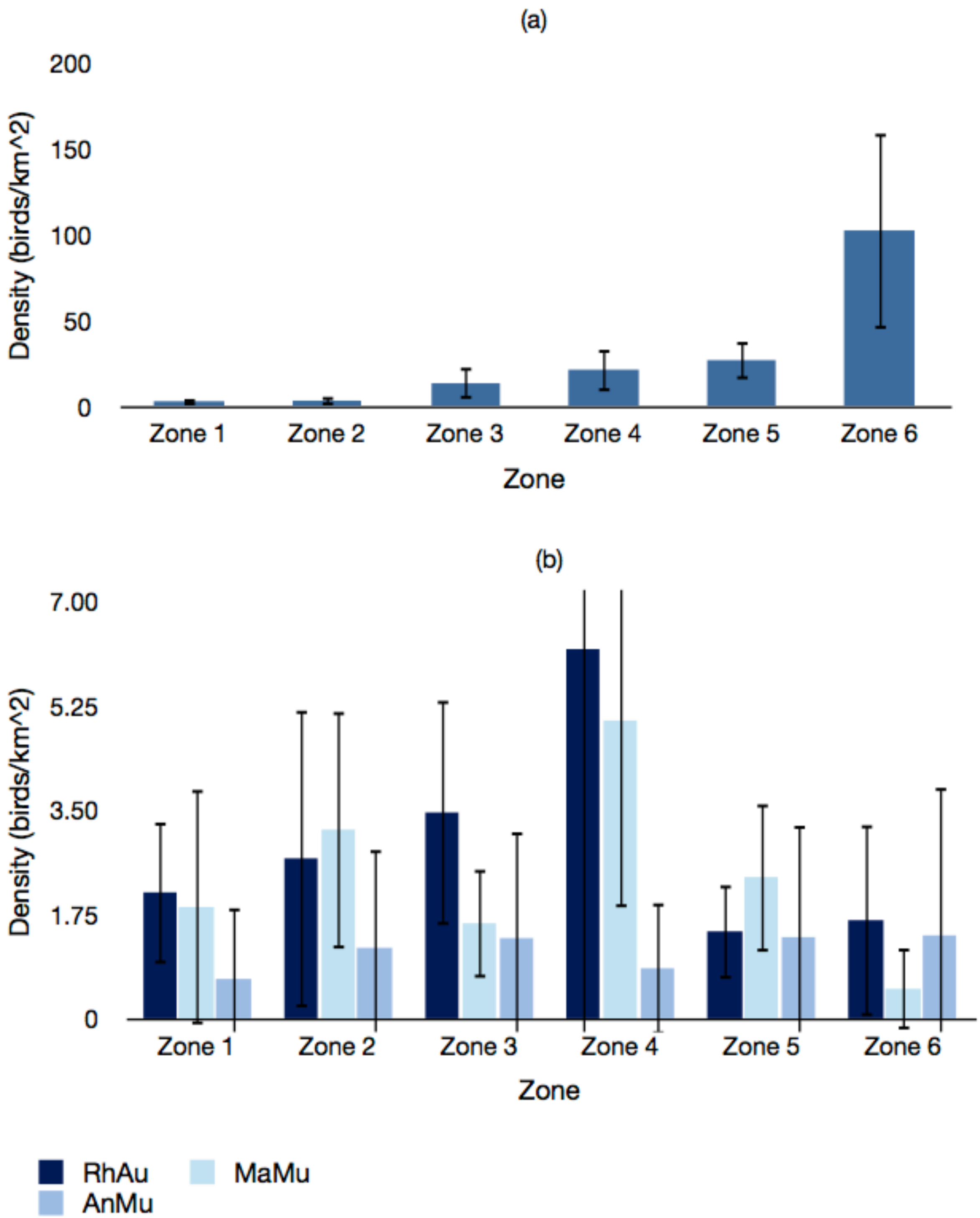


Figure 8: Spatial distribution of a) Common Murres, and b) other alcids in San Juan Channel. Error bars represent a 95% confidence interval.

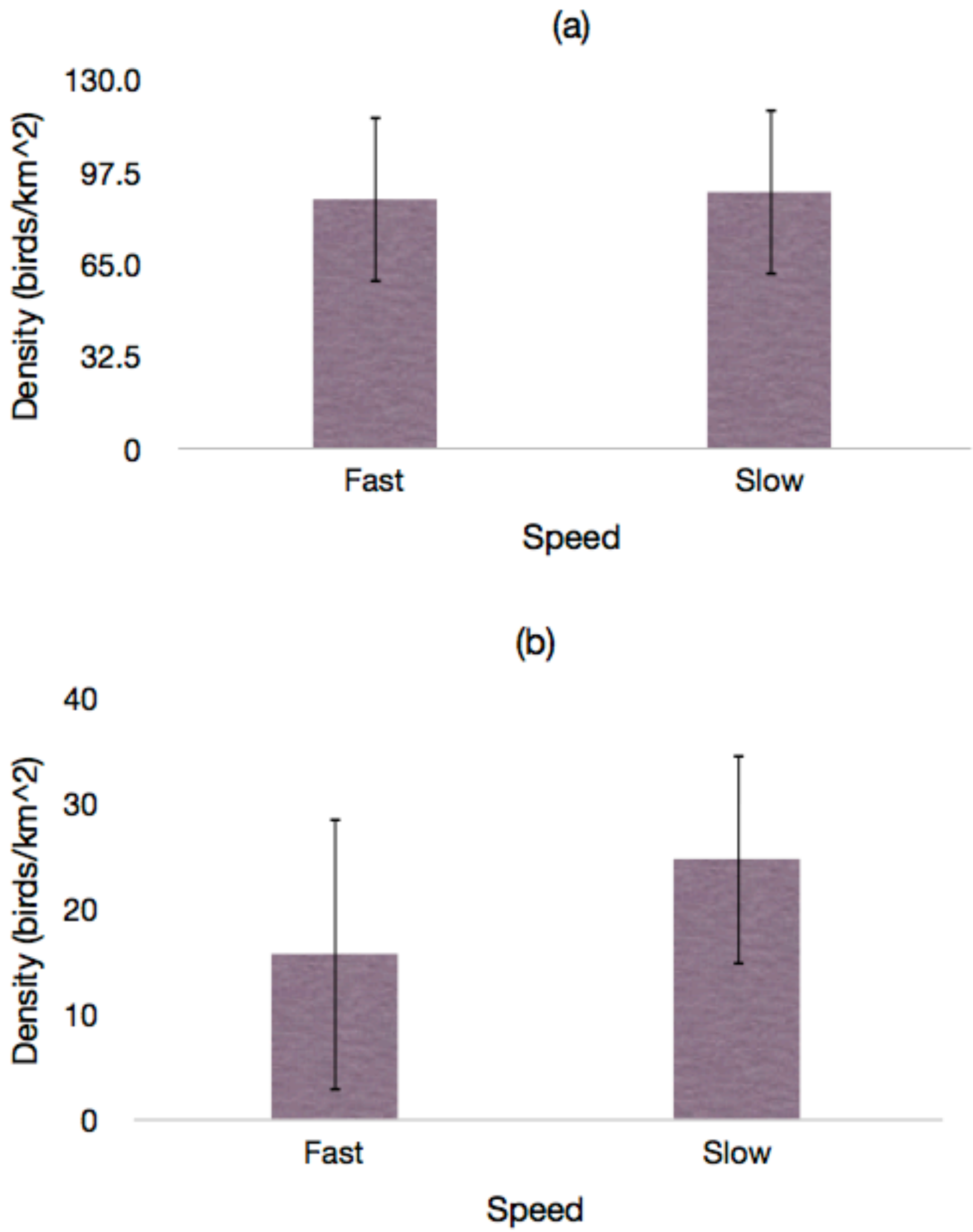


Figure 9: Comparison of mean densities on fast and slow tidal currents in 2013 of a) all birds, and b) Common Murres. Error bars represent a 95% confidence interval.

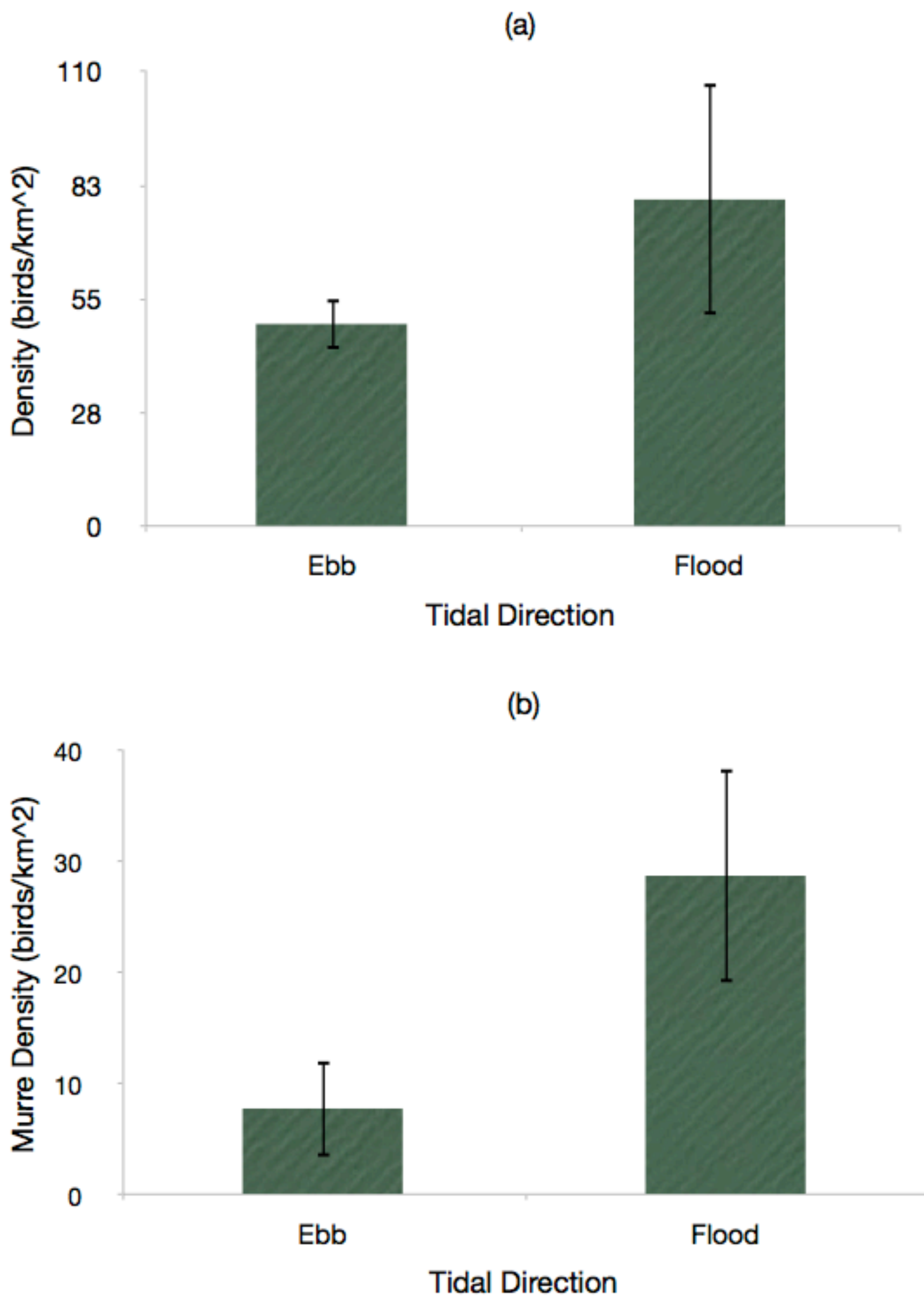


Figure 10: Mean densities in 2013 on ebbing and flooding tides of a) all birds, and b) Common Murres. Error bars represent a 95% confidence interval

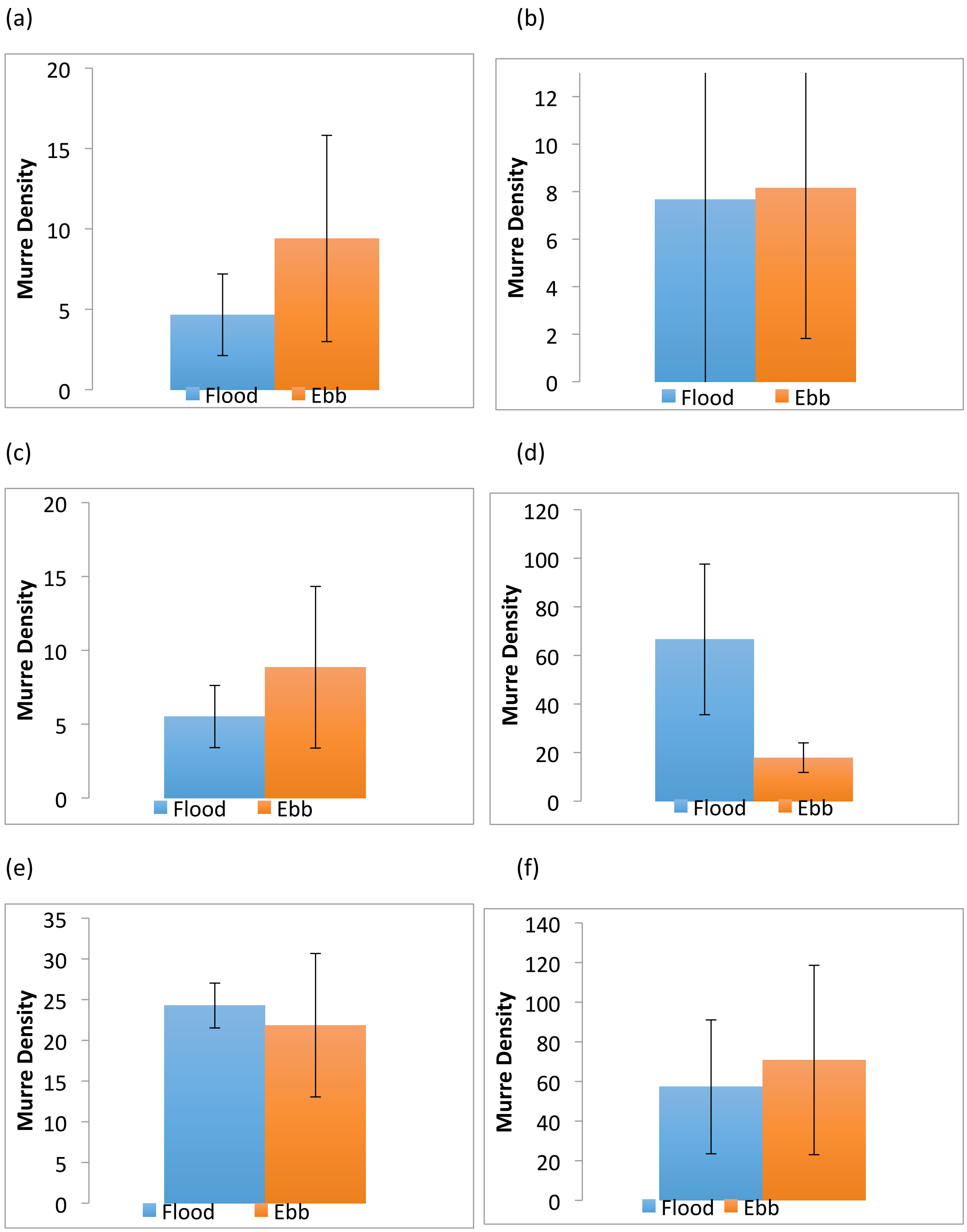
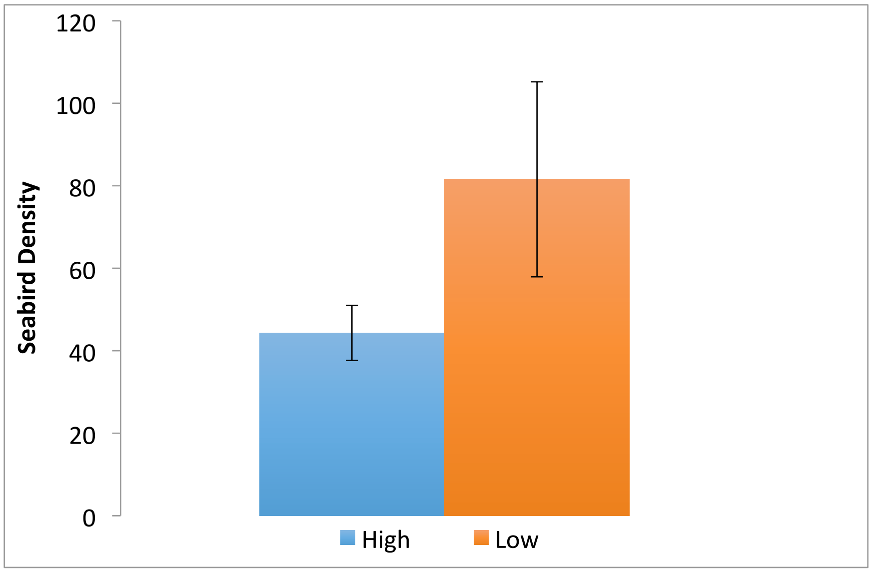


Figure 11: Mean Common Murre density over flooding an ebbing tides from (a)2007 to (f) 2012. Error bars represent a 95% confidence interval.

(a)



(b)

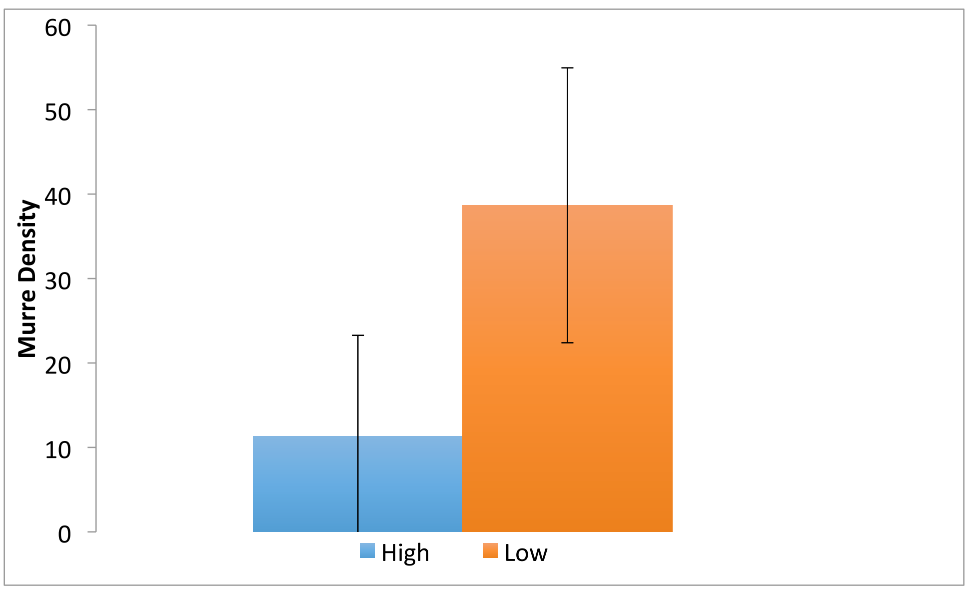


Figure 12: Mean density of (a) all seabirds, and (b) Common Murres over days of high and low tidal exchange. Error bars represent a 95% confidence interval.

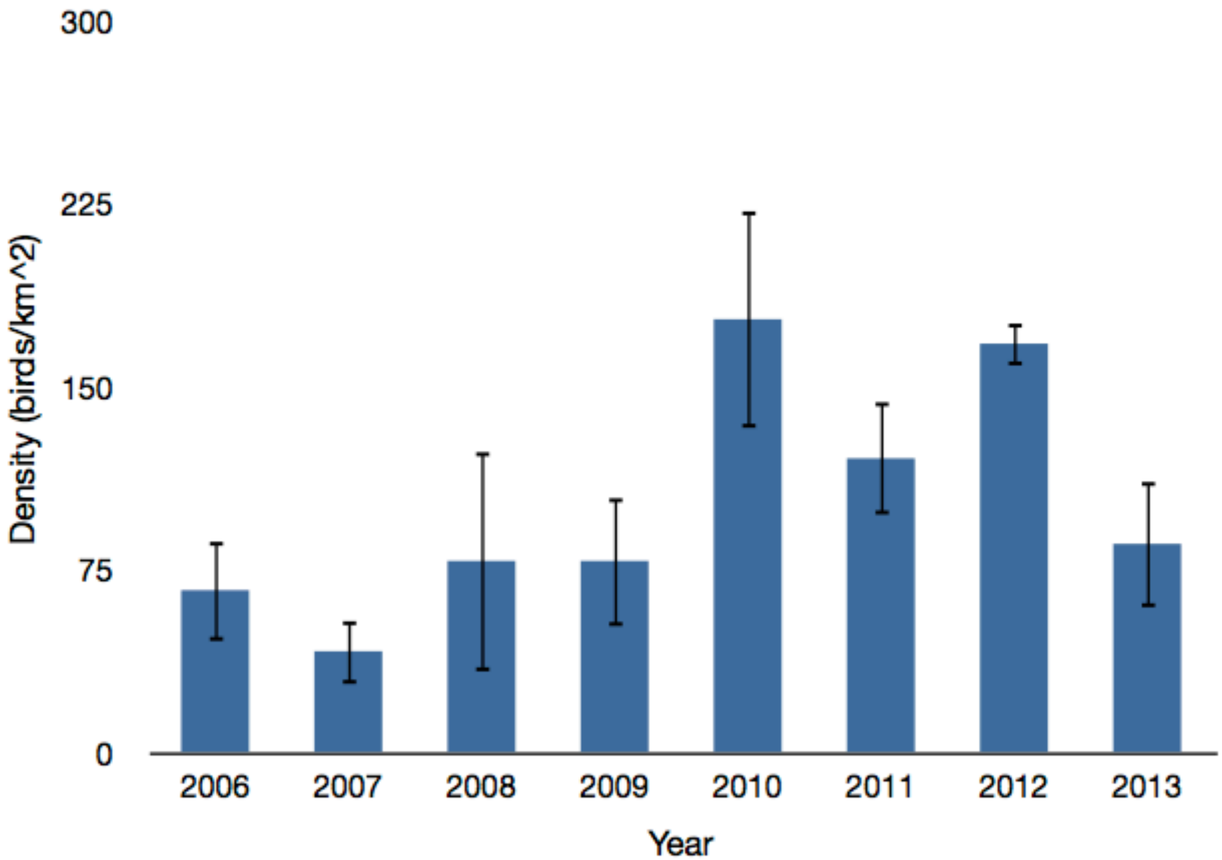


Figure 13: Interannual abundance of seabirds in San Juan Channel 2006-2013. Error bars represent a 95% confidence interval.