Effects of tidal phase on zooplankton abundance in Cattle Pass, WA

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Abstract

Zooplankton in Cattle Pass are advected from two water sources. Water from the Juan de Fuca Strait enters the pass from the South during flooding tides, while water from the Strait of Georgia enters from the North during ebbing tides. The questions I am interested in answering are: how does the marine influence of the Juan de Fuca Strait and the estuarine influence of the Strait of Georgia affect the abundance of zooplankton in Cattle Pass? Do tidal processes affect the abundances of zooplankton in Cattle Pass? Is zooplankton abundance correlated with upper trophic level foraging? I based my hypothesis on several assumptions based on conclusions of a study from 1995 to 1997 by Zamon: water density fluctuations in San Juan Channel are evidence that tidal currents affect the source from which plankton is derived. Flooding tides mix colder, saltier water from Juan de Fuca into San Juan Channel. Tides create predictable patterns of zooplankton availability for planktivorous animals (Zamon 2000). I hypothesized that ebbing tides advect zooplankton from the Strait of Georgia while flooding tides advect zooplankton from the Juan de Fuca Strait. Zooplankton will be more numerous in the more oceanic waters during flood tide. I tested this hypothesis by analyzing zooplankton tows collected during flooding and ebbing tides.

Keywords: zooplankton, tides, strait, year, abundance

Introduction

The question I propose to answer is if more zooplankton are advected during flooding tides from the Juan de Fuca Strait and less zooplankton are advected during ebbing tides from the Strait of Georgia. Zooplankton are organisms suspended in the water column and moved by tides and currents. Tides create foreseeable fluctuations in plankton abundance, which make it possible to predict changes in food availability for planktivores (Zamon 2000). Zooplankton are good indicators of water quality because they respond more quickly to environmental change than fish do (Gannon et al. 1978). They may pass their entire life cycle as plankton, such as copepods, or only a portion of it, like eggs or larvae, and these are called meroplankton (Wickstead 1976). I propose to test the hypothesis that zooplankton will be found in greater abundance during flooding tides and in lesser abundance during ebbing tides.

To test this hypothesis I will sample water profiles and zooplankton from 3 stations with 3 net pulls at each station during both flooding and ebbing tides from June through August. This research is important because zooplankton is the available food source of secondary consumers in food webs, and therefore connects the autotrophic phytoplankton to the larger animal marine life (Zamon 2000). Zooplankton play a vital role in food webs connecting the energy of autotrophic phytoplankton to the macroscopic animals. Studying current and tidal effects will allow the movement patterns of zooplankton to be better understood and better correlated with the foraging habits of secondary and tertiary trophic level predators, like fish, such as salmon, harbor seals, and seabirds.

Tides and current largely control the movement of plankton. Zooplankton circulate throughout the water column which connects autotrophic phytoplankton to the deep ocean organisms. Phytoplankton needs essential nutrients such as nitrates and phosphates, which are richly abundant in the deep ocean (Cases, et al 2002). In order for the phytoplankton to have access to these nutrients, upwelling must occur (Wickstead 1976). Deeper water ascends to the surface as the nutrient-rich water descends where it sustains zooplankton throughout the water column (Wickstead 1976). Cattle Pass receives estuarine water from the North and marine water from the South. The different water densities causes stratification, which is disturbed in Cattle Pass due to the strong tidal currents.

Physical processes, such as tidal forcing and estuarine circulation, mix water from different sources, affecting the abundance and biodiversity of plankton. Biodiversity refers to the proportion of each type of zooplankton that composes each sample. Cattle Pass, a channel in the San Juan Islands in Puget Sound, is fed from the North by the estuarine Fraser River and from the South by the oceanic Strait de San Juan de Fuca. Both these water bodies deposit into the San Juan Channel, which is north of Cattle Pass, creating a very stratified water environment. Zamon found that strong outflow from the Fraser River forces deep nutrient-rich ocean water into the channel through estuarine circulation (Zamon 2000). Zooplankton-rich water is forced to the surface through upwelling, the dominant circulation process in the summer (Sabatini, et al 2004), increasing abundance and biodiversity at the surface, especially of calanoid copepods (Gehman 2005). These influxes of water from the Fraser river and the San Juan de Fuca Strait cause a large amount of water to flow through the narrow channel of Cattle Pass causing a heavily mixed area with strong and fast currents, which makes it an interesting site to study the effects of mixing on plankton abundance and biodiversity. Availability of plankton affects the ability of larger prey, such as fish, seals, and birds, to obtain food.

The amount of mixing will be measured by variance in temperature and salinity. A large difference in temperature or salinity indicates a large degree of mixing, while a small difference indicates a small degree of mixing. Mixing brings about constant nutrient and salinity redistribution. If larger variation in taxonomic groups of zooplankton is seen since the mid-nineties then there is probably more estuarine circulation because more nutrients would be brought up from the deep ocean, which would attract more zooplankton. If less variation is seen, then there is probably less oceanic mixing. Run off from the Fraser River might increase variation in taxonomic groups of zooplankton by bringing in species that are more common in fresh water and less common in seawater.

Similar studies have been done in the autumn months of previous years in the San Juan Channel, north of Cattle Pass. Both Wright and Zamon found that tidal height has a positive correlation with abundance of calanoid copepods and arthropod nauplii, with an increase in calanoid copepod abundance during flood tides and a decrease during ebb tides (Wright 2005). This conclusion was made twice, once during Zamon's study from 1996 to 1997 and again during Wright's study in 2005. Another study by Gehman compared plankton samples farther north in the channel and farther south in the channel, and found that biodiversity was greater in the North with the estuarine influence from the Fraser River, while abundance was greater in the South with the oceanic influence from the Strait of San Juan de Fuca (Gehman 2005). I will elaborate on these studies to further understand plankton dynamics in the San Juan Islands during the summer months.

Methods

Study Site

Cattle Pass is a region of the San Juan Islands, WA, south of San Juan Channel. It is a channel fed from the North by the estuarine Fraser River and from the South by the oceanic San Juan de Fuca Strait. These large influxes of water enter the San Juan Channel and consequently through the narrow channel of Cattle Pass creating a heavily stratified, mixed area with strong and fast currents. In the San Juan Channel, flooding currents flow South to North, while ebbing currents flow North to South (Zamon 2000). Cattle Pass is rich in biodiversity featuring marine mammals such as seabirds, harbor seals, harbor porpoises, and salmon.

Water Profiling

I measured the amount of mixing of stratified water in Cattle Pass by taking water profiles using a conductivity-temperature-depth instrument (CTD), the Seabird SEACAT SBE-19 plus, from three stations along a 1.5 m West to East transect at 80.0 m from June to August at flood and ebb tides. The CTD was lower by hand at a rate of 1.0 m/s. CTD profiles were made to depths from 30.0 meters at the Harbor Rock West and Harbor Rock East stations nearer to the shore and up to 80.0 meters and Harbor Rock Central. The CTD measures the influence of water from both the Juan de Fuca Strait and the Strait of Georgia.

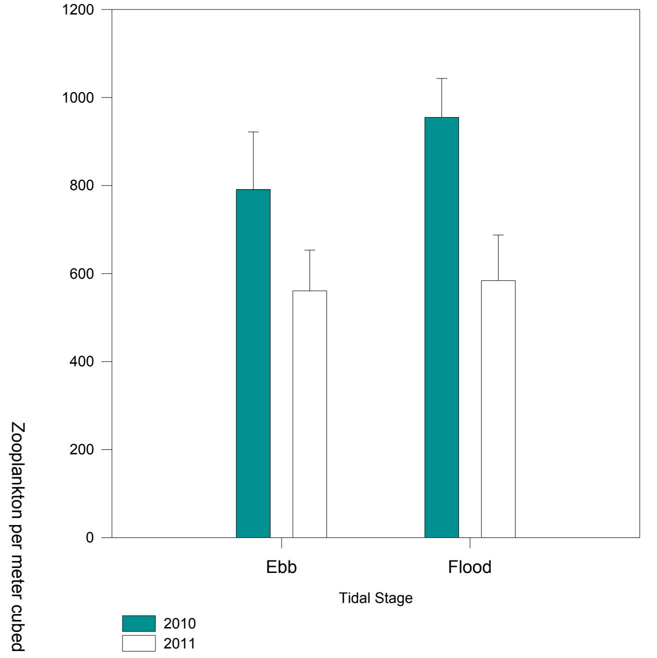
Net Sampling of Zooplankton

Zooplankton samples were gathered from 3 stations, “Harbor Rock East”

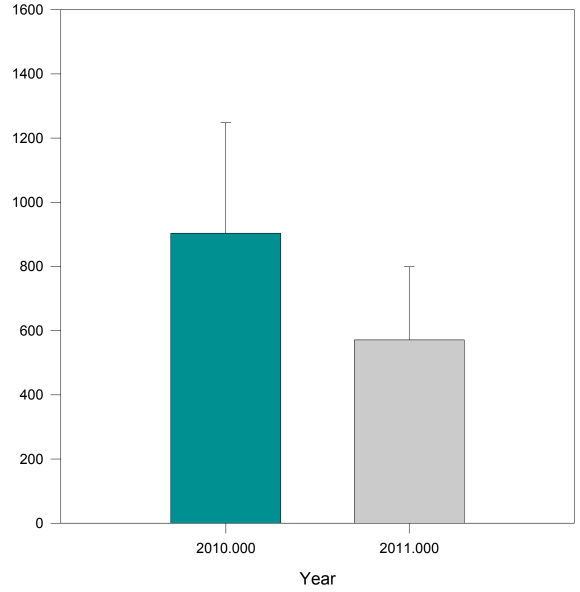
(HRE), “Harbor Rock Central” (HRC), and “Harbor Rock West” (HRW), with 3 net pulls at each station during both flood and ebb tides during the months of June through August. I hand-hauled a 0.25 m diameter ring net with a 335 m mesh. I preserved the plankton samples in 5% buffered formalin and filtered seawater after collection (Zamon 2000). The plankton were stored in a clean, plastic jar and kept in cardboard boxes in a cool dry room. I rinsed the plankton from mesh of the net into the bucket of the net using a hand-pumped, herbicide-type sprayer filled with pressurized seawater (Zamon 2000). All zooplankton samples were labeled. In lab the zooplankton were filtered from the formalin buffered seawater solution using a mesh filter and a seawater pump. Each sample was then divided into 10 mL portions to be counted in a petri dish. The abundance and types of all identifiable taxonomic groups of zooplankton were determined using a light microscope and recorded to extrapolate their proportions in each sample during flood and ebb tides in coordination with their given tidal height.

Estuarine circulation carries zooplankton from the Strait of Georgia to Juan de Fuca Strait, which causes a decrease in zooplankton in both water bodies. More runoff from the Frasar River increases phytoplankton and decreases zooplankton abundance. Moreover, zooplankton abundance in Juan de Fuca is always greater than that in the Strait of Georgia. Cattle Pass is an area where heavy mixing occurs because it is so narrow with a high volume of water flowing through it. This brings the Pacific Ocean nutrients from the Juan de Fuca Strait up to the surface (Li 2000).

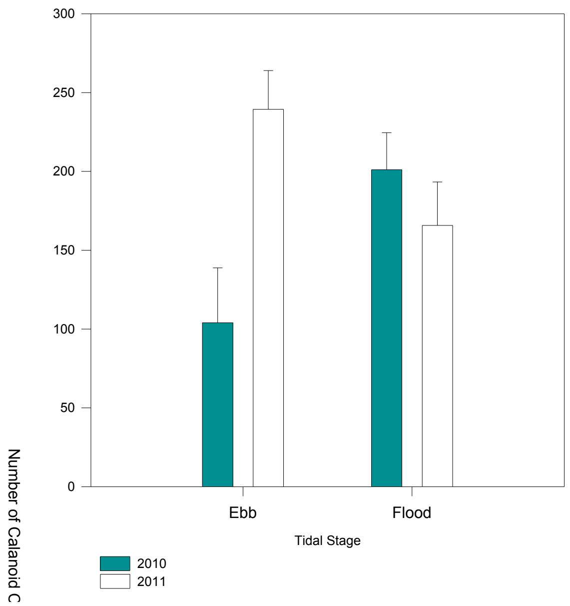
Results



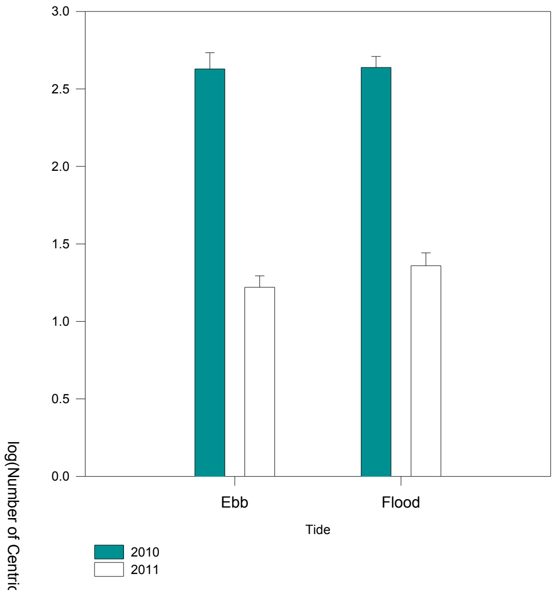
Dependence of Zooplankton Abundance on Year and Tide



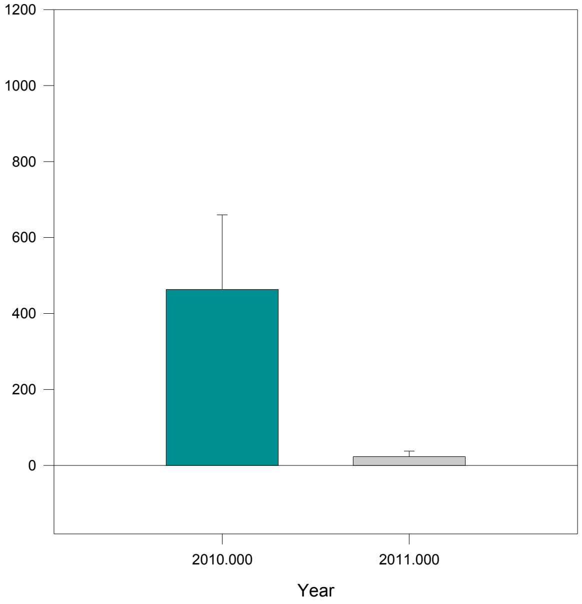
Dependence of Zooplankton Abundance on Year



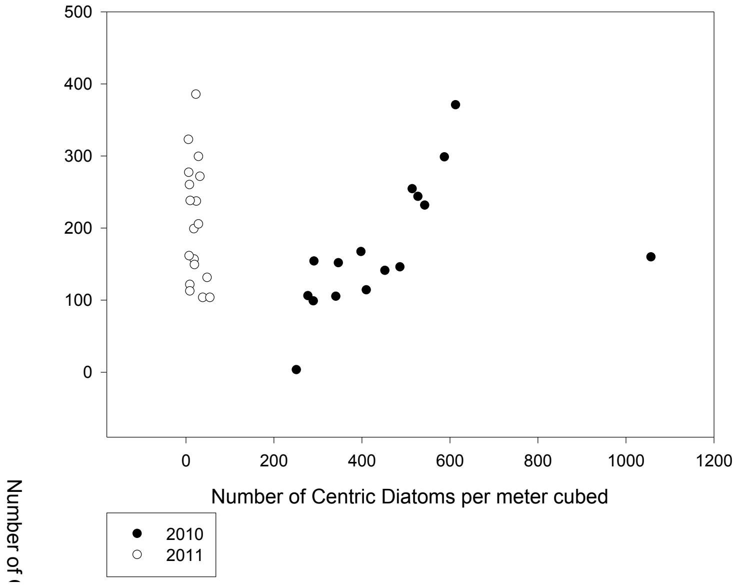
Dependence of Calanoid Copepod Abundance on Year and Tide



Dependence of Centric Diatom Abundance on Year and Tide



Dependence of Centric Diatom Abundance on Year



Dependence of Calanoid Copepod Abundance on Centric Diatom Abundance

Discussion

A t-test performed on total zooplankton counts from the early summer period of both 2010 and 2011 indicated there was a significant difference of zooplankton abundance based on year. With a highly significant P value of 0.002, t = 3.357, and d.f. = 32. “The difference in the mean values of the two groups is greater than would be expected by chance; there is a statistically significant difference between the input groups (P = 0.002)” (SigmaPlot). A Two Way ANOVA indicated a significant difference of year within the flooding tide; with t = 2.861 and P = 0.008. While year within flood was also significant; with t = 2.730 and P = 0.011.

A One Way ANOVA investigating the dependence of centric diatom abundance on year indicated a significant difference; with t = 9.485 and P < 0.001. The abundance of centric diatoms was roughly between 400 and 500 centric diatoms per meter cubed in 2010 and < 100 centric diatoms per meters cubed in 2011. I performed a Two Way ANOVA on centric diatom abundance based on the interaction between tide and year using the raw data counts of centric diatoms and it failed both the Normality test and the Equal Variance test. I then took the log of the raw counts data and the test passed the Normality test and failed the Equal Variance test. I then took the log of the raw data and came up with the following results. The preliminary investigation of the test indicated that tide is not a factor in determining centric diatom abundance; with P = 0.382. The interaction is not significant either with a P value of 0.448.

I performed a Two Way ANOVA to determine the dependence of calanoid copepod abundance based on the interaction of year and tide. The test indicated that the interaction makes it so that the change in abundance cannot be significantly attributed to one factor “because the size of a factor's effect depends upon the level of the other factor. The effect of different levels of Year depends on what level of Basic Tide is present. There is a statistically significant interaction between Year and Basic Tide. ($P = 0.005$)” (SigmaPlot). There was a significant difference in tide within 2010 and year within ebb. The interactions of year within ebb and flood also proved to be significant with $P < 0.001$ in both cases.

I found that the dependence of total plankton abundance, which includes the centric diatoms that our net captures, was dependent on year but not tide. There was more plankton in 2010 than in 2011. This could be because of a bottom-up interaction or a top-down interaction. A bottom-up interaction could indicate a possibility that there was a delayed phytoplankton bloom, therefore, a delayed food source. There may have been a cool and cloud covered summer and therefore a slow spring transition, and therefore, less phytoplankton, and so less zooplankton (Mass 2011). A top-down interaction could indicate more seabird foraging, which would cause less forage fish therefore increasing the numbers of zooplankton. In 2010 the mean number of bird forage flocks per survey was 0.628 and 14% of surveys had >1 bird forage flock. In 2011 the mean number of bird forage flocks per survey was 0.737 and 21% of surveys had >1 bird forage flock.

In looking at the dependence of calanoid copepod abundance on year and tide, I found a significant difference in the interaction between year and tide, and especially in tide within 2010 and 2011, and year within ebb. This may be somewhat attributed to a difference in amount of Fraser River runoff. In June and July of 2010 there was about 5000 meters cubed/sec of runoff, while in June and July of 2011 there was about

9000 meters cubed/sec (*Fraser River at Hope [BC] (08MF005)*). This could affect the circulation of calanoid copepods to the surface layer.

In looking at the dependence of centric diatom abundance on year I found a significant difference based on year but not tide. The abundance of centric diatoms was roughly between 400 and 500 centric diatoms per meter cubed in 2010 and < 100 centric diatoms per meter cubed in 2011. This may be because of a diluted from increased runoff from the Frasar river in 2011, may be because there were more copepods present to eat them, may be because of a late bloom, or may be because another species of phytoplankton is dominating that our net does not capture.

My findings were different from Zamon study in that she found bottom-up interaction while I found top-down interaction (Zamon 2000). It is possible that the system has reorganized between summers. I found a possible correlation between seabird foraging and zooplankton abundance in 2010 and 2011. This supports the Zamon study that tides affect availability of zooplankton and foraging success (Zamon 2000). I found a possible negative correlation in that more foraging means less plankton.

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