Diving Behavior in Pelagic Cormorants in Summer near San Juan Island, WA

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Abstract

This study, conducted on San Juan Island, Washington during late summer, assessed variation in diving behavior of pelagic cormorants relative to time of day and tidal currents. Mean dive lengths did not differ significantly between morning and afternoon periods. However, dive lengths were longer during ebb versus flood tides and dive lengths also increased with the speed of water currents where diving occurred. To explore the possibility of physiological adaptations to low oxygen availability, the length of rest periods following dives was measured to see if pelagic cormorants displayed dive time to rest time rations that deviated from the a 1:1 ratio typical of aerobic diving. Because they do not strictly adhere to the predicted 1:1 ratio of aerobic dive time to rest time, pelagic cormorants likely have additional adaptations that allow them to cope with reduced access to oxygen.

Keywords

Cattle Pass, diving birds, foraging behavior, Hunt's Point, Pelagic cormorant, Phalacrocoracidae, *Phalacrocorax pelagicus*, San Juan Island, tidal currents

Introduction

The pelagic cormorant (*Phalacrocorax pelagicus*) is the smallest member of the Phalacrocoracidae family that occurs in the San Juan Archipelago of Washington state. Other local species of cormorants include two larger species, Brandt's cormorant (*Phalacrocorax penicillatus*) and double-crested cormorant (*Phalacrocorax auritus*).

They are most commonly found within a few kilometers of shore (Ainley et al. 1981, Hobson 1997).

Although primarily piscivores pelagic cormorants may also feed on benthic invertebrates in shallow, rocky coastal areas, especially when there is competition from other species of cormorants(Ainley et al. 1981). In British Columbia, Hobson and Sealy (1985) observed that foraging usually occurred in water 2-5 meters deep, but that some individuals foraged in water up to 20 meters deep. The average dive time reported for adult cormorants in this study was 34.9 secs. with a standard deviation of 4.1 secs.. This is similar to the findings of Dow (1964), who reported a mean dive time of 45.3 secs. with 1.35 SE for depths between 1.5 and 6.1 meters based on a study done near Vancouver, British Columbia, Canada. Pelagic cormorants are thought to propel themselves mainly with their feet, holding that their wings slightly away from the body to aid in underwater steering (Gabrielson and Lincoln 1959, as cited by Hobson1997). Although they are normally solitary feeders, pelagic cormorants may join multi-species flocks to feed on schools of small to medium-sized fish, such as smelt and herring. Because they can dive deeper than other species in such flocks, cormorants may remain in a feeding area after other species have given up foraging as unprofitable (Gaston 2004).

Cormorants have evolved adaptations to maximize dive efficiency and to moderate the effects of buoyancy and oxygen limitations during diving. Physiological adaptations for efficient diving include a relatively heavy body, well-developed thigh and hip muscles as well as fully webbed, “totipalmate” feet (Hobson 1997). Also, cormorants have feathers that allow water penetration, enabling them to reduce the energy costs of overcoming buoyancy (Mahoney 1984). However, allowing water to penetrate through feathers makes returning to the surface more energetically expensive and reduces the feathers' ability to insulate effectively; it also means that the pelagic cormorant must spend time drying their wings (Gaston 2004). For most divers, dives are followed by periods of rest at the surface before the start of the next dive. Research has shown that a 1:1 ratio between time spent underwater and rest time between dives should exist if an organism is using only aerobic respiration (Kooyman and Ponganis 1997). If more time is spent diving than resting, it implies that the bird has some sort of physiological adaptation to deal with oxygen depletion or the metabolic byproducts (lactate, nitrogen) that the bird accumulates to remain underwater (Croll et al. 1992).

My objective in this study was to observe diving behavior of pelagic cormorants. Specifically I measured the length of dives by individual birds and assessed variation in response to time of day (morning vs. afternoon) and tidal conditions (ebb vs. flood). To explore the possibility of physiological adaptations to low oxygen availability, I also measured the length of rest periods following dives to see whether pelagic cormorands displayed dive time to rest time rations that deviated from the predicted 1:1 norm.

Methods

I conducted this study on the west side of Cattle Pass at the south end of San Juan Island, Washington, USA (Fig. 1). The location that I observed from is colloquially known as Hunt's Point (Fig. 2) after the owner, Dr. George Hunt. I used two sites: one site enabled me to look north (48°27.899'N, 122°57.620'W). The other site allowed me to look south (48°27.856’ N, 122°57.589’W). Most of my observations were conducted from the south-facing site because cormorants were more frequent there.

I observed diving cormorants during 12 observation periods from 11-21 August 2011. Observation periods spanned a range of daylight hours and tidal conditions (morning vs. afternoon, ebb vs. flood) and I recorded information about weather, tide, and wind conditions for each period. Cormorant observation data were collected only when a single cormorant was visible in the observation area to eliminate the possible confusion associated with observing multiple diving individuals. Observation of a focal bird was discontinued when it moved out of visual range.

I recorded three types of data about the pelagic cormorants. I conduced three-minute focal individual surveys where I noted a particular individual cormorant’s behavior every 10 sec. to quantify how their time was spent. The behaviors that I tracked were time spent on water surface (floating – FL), diving (D), wing drying (WD), preening (P), and flying (F). During the focal individual survey, I also timed the length of individual dives during the focal individual survey. Additionally, I timed the lengths of individual dives and the rest periods that followed.

My null hypothesis was that the mean dive time would be the same for morning and afternoon as well as for ebb and flood. The research hypothesis was that they are not equal because foraging conditions and prey availability may vary throughout the day or with tidal conditions. Dive times were grouped into four categories: morning, afternoon, ebb, and flood. To assess differences in mean dive time relative to time of day (morning vs. afternoon) and relative to tide phase (ebb versus flood), I used t-tests (equal variance, two-tailed). Probabilities with Type I error of 0.05 or less are considered statistically significant.

I used a post hoc power analysis to determine the strength of the tests (G*Power, 2010). Effect size was calculated as the difference between the sample means divided by the pooled standard deviation. I also calculated the sample sizes necessary to have an experiment with adequate power to be confident of the results at a probability of 0.05. I used a Chi-squared test to test the significance of probabilities. Linear regression analysis was used to test relationships between the dependent and independent variable. I did a natural log transformation of the raw data to linearize the fit of the regression as much as possible to appropriately represent the data without use of a more complex model.

Results

Dive Times

Dive times did not differ significantly between morning and afternoon periods (Table 1). Average dive time did vary significantly based on tidal conditions with mean dive time being greater during ebb versus flood ides (Table 1). The proportion of observations made in the morning and afternoons are 0.30 and 0.70 respectively (Chi-square test of probabilities < 0.001). Mean dive times of pelagic cormorants increased with current speed ($P<0.001$, R^2 of 0.39, Fig. 3). Proportions for ebb and flood are 0.30 and 0.70 (Chi-square test of probabilities < 0.0001).

Dive/Rest Ratio

The only behaviors that I observed during the focal animal survey were diving and resting. For each three-minute survey, I calculated the percentage of time that each individual spend above and below the water. On average, focal individuals spent 53% of the time on the surface and 47% of the time diving (probability 0.12, power 0.47). The mean observed dive/rest ratio is 1.07 (standard error 0.12). The minimum ratio was 0.14 and the maximum was 2.6. A comparison of average dive ratios (dive time:rest time) for morning, afternoon, ebb tide, and flood tide can be found in Fig. 4; a comparison of average percent of time spent diving during daily time periods and tidal conditions can be found in Fig. 5.

Discussion

Results of this study indicate that pelagic cormorant dive times do not vary significantly between morning and afternoon periods. However, pelagic cormorants did dive for longer periods during ebb tides versus flood tides and when the current speed was faster. Longer dive times could be a function of pelagic cormorants needing more time to locate and catch prey when the current is stronger or may indicate that feeding during ebb tides or when the current is running faster is more profitable. Spending a higher proportion of time diving might occur when foraging is especially profitable. While most diving birds avoid areas of strong current and turbulent water, pelagic cormorants can be found foraging in such areas although they do not appear to actively seek them out (Holm and Burger 2002).

The difference in mean dive time between morning and afternoon cannot be considered conclusive because of the low power of the experiment, meaning that there is a high probability of a Type 2 error (b=0.87) and that the null hypothesis may not have been rejected even though it was false. This low power is a function of small differences between the means as well as the low sample size and high variability of the dive times. Assuming that the probability of making an observation is similar to what I discovered in this investigation is accurate (sample ratio 2.4), another researcher completing the same study would need samples sizes of 231 and 533 to achieve high confidence (98%) with high power (0.8). To achieve even a minimal level of rigor (power of 0.6 with 67% confidence), the sample size should have been 100 for the morning and 142 for the afternoon. I spent a total of 7.75 hours observing in the morning to obtain 20 dive times; to obtain 100 would take about five times longer (nearly 40 hours). In the afternoon, I spent a total of 11 hours observing to obtain 47 dive times. To obtain the 142 dive times necessary for an adequately powered study, I would likely have needed to observe for about three times longer (33 hours).

The effect of tidal current on dive time is significant but the power of the comparison of dive times during ebb and flood tides is low. To have high power at this level of probability would require sample size of 33 (ebb) and 107 (flood). I spent a total of 10.25 hours observing during ebb tides to get 18 dive times and a total of 10.5 hours observing during flood tides to get 58 dive times. This indicates that more observation time was needed to achieve a result with high confidence and high power. From these data, it appears that cormorants are more likely to be foraging in the study area during flood tides.

For the highly significant relationship between dive time and current speed (probability 0.001), the R^2 indicates that 39% of the variability between dive time and current speed is explained by this single independent variable. Based on these data, I can conclude with high confidence that dive time increases with current speed. This indicates that cormorants may need more time to get to the depth where their preferred prey can be found when the current is stronger.

Very different dive times and dive ratios might be obtained over a longer period of time or spanning different seasons due to variability in prey type and availability. Some diving birds may use different foraging strategies, such as longer dives or multiple dives in a short time period, for different types of prey. This is the case in great cormorants, and could also be a factor in diving behavior of pelagic cormorants (Cosolo et al. 2010).

Morning dive ratio shows a clear differentiation from afternoon, ebb and flood dive ratios (prob. 0.016, power 0.33, Fig. 4). The ratio of 0.65 (se 0.14) is clearly less than the ratio of 1:1 that has been established in the literature (Kooyman and Ponganis 1997). The lower confidence limit for afternoon dive ratio is greater than the 1:1 ratio -- suggesting that the afternoon exceeds the 1:1 ratio. The dive ratios for ebb and flood tides do not differ from the 1:1 ratio. Similarly, the proportion of time spent diving in the morning is less than in the afternoon (prob. 0.058, power 0.48). There is no difference in proportion of time spent diving between ebb and flood tides. However, although there is evidence that pelagic cormorants do deviate from the established 1:1 ratio in afternoon dives, I did not fully investigate whether the time before a dive or after a dive is more important in dive length determination. Ideally, in a future study I would keep track of a long series of sequential dive and rest periods to better evaluate trends in dive length and their relationship to long and short surface rest periods.

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Tables

Table 1: Summary of statistical results for comparisons of mean dive times between daily time periods and tidal phases for pelagic cormorants in the San Juan Islands, Washington

	Morning	**Afternoon**	**Ebb**	**Flood**
Sample size	20	47	18	58
Mean	31	34	38	32
Standard Error	2.454	1.514	1.970	1.370
P(T<=t)	0.4112		0.0427	
Power	0.128		0.535	
Effect size	0.22		0.56	

Figures

Figure 1: Location of pelagic cormorant observations on San Juan Island, Washington

Figure 2: Location of north and south facing observation sites on Hunt's Point at the south end of San Juan Island, Washington

Figure 3: Relationship between current speed in knots and pelagic cormorant average dive time

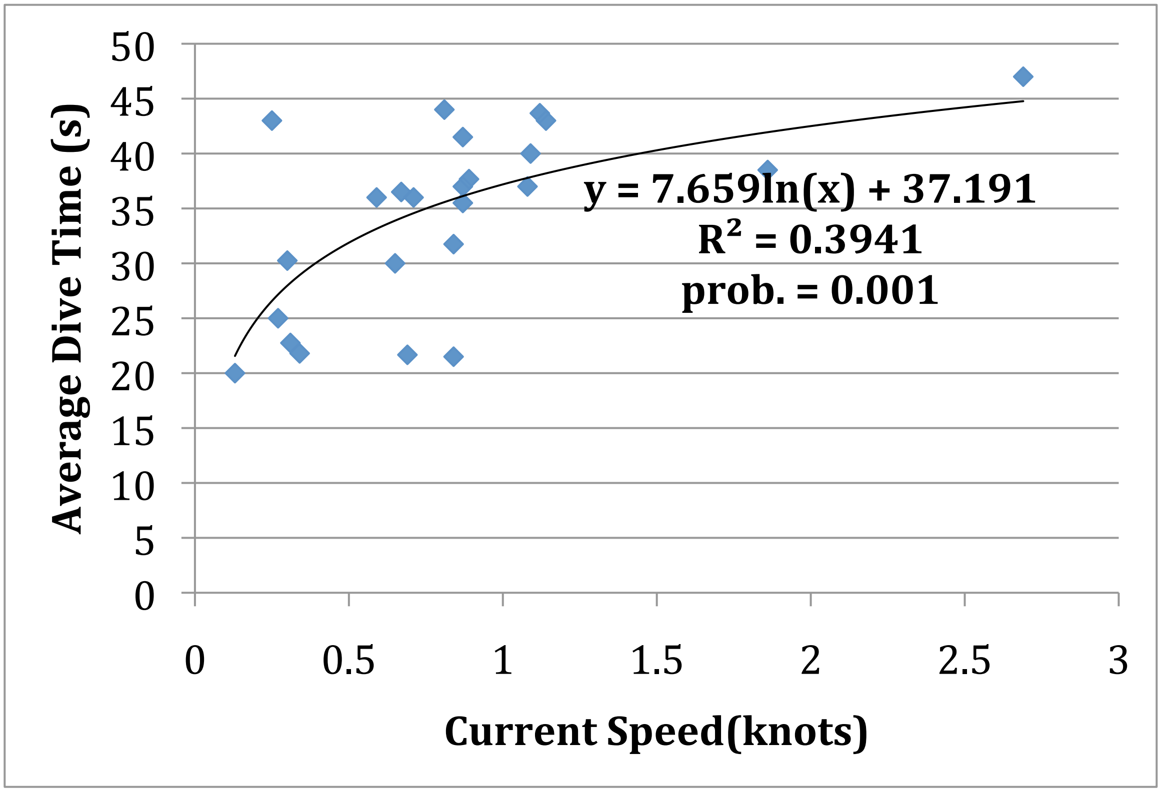


Figure 4: Comparison of dive ratios (dive time:rest time) between daily time periods and tidal phases for pelagic cormorants in the San Juan Islands, Washington. Shown are the sample mean and confidence limits for 1 standard error. Sample sizes are 7, 23, 5, and 25 for morning, afternoon, ebb, and flood respectively.

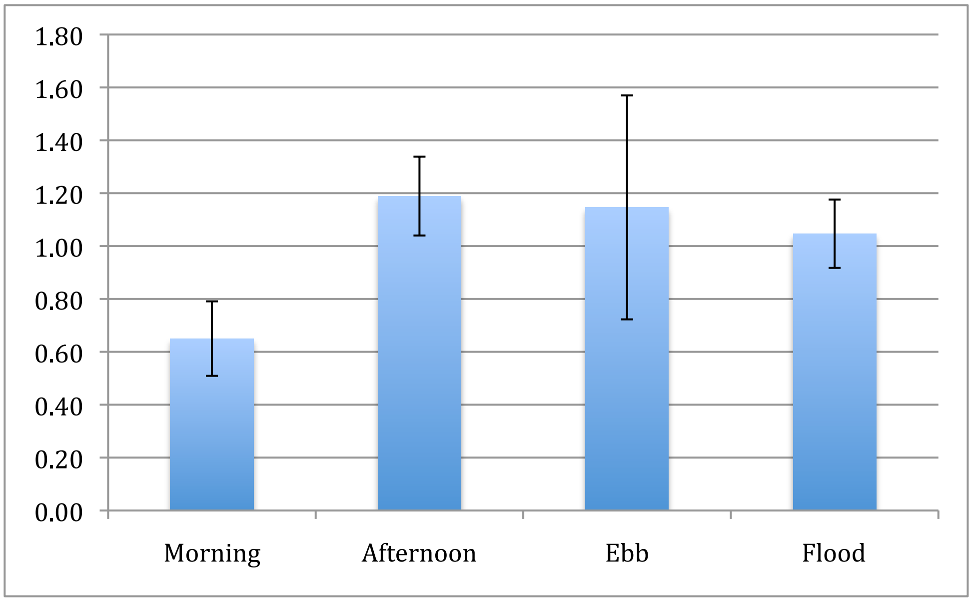
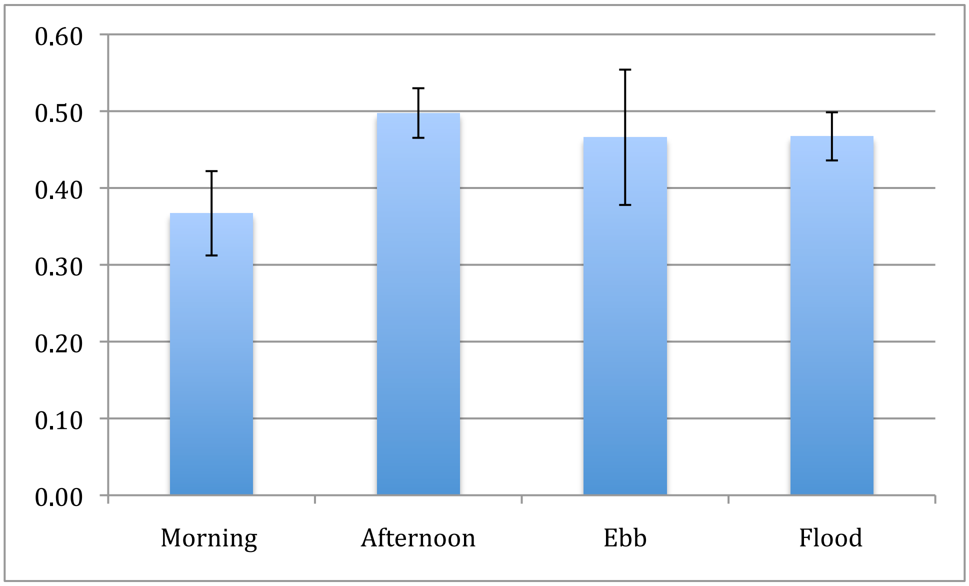

1.80
1.60
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Morning
Afternoon
Ebb
Flood

Figure 5: Comparison of average percent of time spent diving during daily time periods and tidal phases for pelagic cormorants in the San Juan Islands, Washington. Shown are the sample mean and confidence limits for 1 standard error. Sample sizes are 7, 23, 5, and 25 for morning, afternoon, ebb, and flood respectively.



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