Dive Behavior of the Double Crested (*Phalacrocorax auritus*) and the Pelagic (*Phalacrocorax pelagicus*) Cormorant at Cattle Pass, San Juan Island, WA

Jeffrey Y. H. Lou[1, 2] and Benjamin C. Pelle[1, 3]

Ecology and Conservation of Marine Birds and Mammals
Summer 2014

[1]Friday Harbor Laboratories, University of Washington, Friday Harbor, WA 98250
[2] School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195
[3] School of Oceanography, University of Washington, Seattle, WA 98105

Contact Information:

Jeffrey Y. H. Lou
School of Aquatic and Fishery Sciences
University of Washington
Box 355020
Seattle, WA 98195-5020
jefflou@uw.edu

Benjamin C. Pelle
School of Oceanography
University of Washington
Box 357940
Seattle, WA 98195-7940
pelleb@uw.edu

Abstract

The dive behavior of the Double Crested Cormorant (*Phalacrocorax auritus*) and the Pelagic Cormorant (*Phalacrocorax pelagicus*) was studied along Cattle Pass of San Juan Island, WA, USA. Dive durations and resting periods were measured for consecutive, sequential dives of each type of cormorant. Comparing the two species, mean dive time was greater for the Pelagic Cormorant. Both species exhibited dive to rest time ratios greater than one (>1) and therefore generate an oxygen debt that must be resupplied after completion of dive bouts. Tidal phase, including tidal height and current speed had an effect on when both species chose to forage. Further analysis of prey abundance and final resting locations in the Cattle Pass region are needed to understand more about the Double Crested and the Pelagic Cormorant's dive behavior in the San Juan channel.

Keywords: Diving birds, Cattle Pass, Pelagic Cormorant, Double Crested Cormorant, Dive and Recovery durations, tidal currents

Introduction

The San Juan channel in Washington's Puget Sound is greatly affected by oceanic influences, resulting in large changes in both tidal height and velocity. This makes for a very biologically rich area that has high concentrations of marine organisms. High abundance of fish and other prey items make this a prime habitat for various seabirds, including the Double Crested Cormorant (DCCO) and the Pelagic Cormorant (PECO). Both species of cormorant are piscivorous, foot-propelled divers that forage mainly in shallow inshore waters (Sapoznikow & Quintana, 2003). The diving ability of these birds is highly dependent on environmental factors, including tidal variations (Ribak et al. 2005, Hobson and Sealy 1985). Both species of cormorants are relatively heavy boned diving birds and must overcome buoyancy restrictions in order to forage.

Our study aims to understand the diving behavior of Pelagic and Double Crested Cormorants. Specifically we looked at the effects of tidal phase on diving abundance to establish under what environmental factors contribute to cormorants' selection of foraging times and locations. We also compared the mean dive durations of both species to distinguish any differences in dive time. Our study also looked at the relationship between dive duration and recovery time and determined the differences and similarities between the species.

Materials and Methods

Study Area

Our study was conducted on the eastern shore of Cattle Pass, a biologically abundant water channel on the southern tip of San Juan Island, WA (approximately 48° 27' 21.11" N 122° 57' 38.95" W) (Fig. 1). This area is a very narrow section of the San Juan passage with high tidal velocity and height variation. Two distinct groups of cormorants (Pelagic and Double Crested) were distinguished on Goose Island, double crested on the western end of the island and pelagics on the southern end.

Survey

Cormorant diving observations were taken in the passage between Goose Island and shore, approximately 50m south of the island, 10 m shoreward of the high velocity current of Cattle Pass (Fig. 1). Land based surveys of foraging cormorants were completed between 9-16 August 2014 during both slack ebb and slack flood tidal phases using 10x binoculars and a 48x tripod mounted scope to confirm species correctness. Stopwatches were used to measure dive times and recovery periods of diving birds in the passage. Dive and recovery times were collected until the bird ended its diving bout or if the bird could no longer be observed. Observations began during different times of day depending on the tidal period, but were collected at the start of slack flood. Data was collected until one hour after the last diving bird was observed. Tidal information was obtained from tides.mobilegeographics.com and MrTides (MaxOSX).

Data Analysis

Regression analysis and a *t*-test of significance ($p < 0.05$) were used to compare the relation between dive duration and recovery time. A *t*-test was also run on the mean dive duration of both species.

Results

Tidal Phase and Abundance

Our results indicate that the abundance of diving cormorants was dependent on tidal phase (Fig. 1). Observations were made at slack flood (low), max flood, slack ebb (high), and max ebb tides. The highest number of diving birds (n=13) were recorded at the start of slack flood (lowest tidal velocity and shallowest water), no birds were observed diving during max flood or ebb tides, and one diving bird was recorded during slack ebb (lowest tidal velocity and deepest water). Current speeds were estimated during each observation period. The lowest current speed was 1.66 knots on 16 August 2014 where a single diving bird was observed during this period. Fastest current speeds during observation were 4.6 knots on 11 August 2014 where 5 cormorants were observed diving.

Dive Duration

Diving Pelagic Cormorants (n = 7) and Double Crested Cormorants (n = 7) were observed in this study. A total of 117 dives and rest time pairs were recorded, 56 for Pelagic Cormorants and 61 for Double Crested Cormorants, respectively. Mean dive duration differed between the species, where the PECO mean duration was 32.6 ± 14.0 seconds, with a range of 6 to 72 seconds, and the DCCO mean dive duration was 23.1 ± 8.1 seconds, with a range of 9 to 50 seconds. Surface times ranged from 5.3 to 74.5 seconds for Double Crested and 6.1 to 45.1 seconds in Pelagic Cormorants. Mean recovery period for Pelagic Cormorants was 18.8 ± 9.7 seconds and 14.7 ± 7.3 seconds for Double Crested.

Dive and Recovery Relationship

Our dive duration and recovery time results indicate that both PECO and DCCO spend a longer period of time diving than resting. Calculating a mean dive to recover ratio showed that both species spent a similar amount of time diving over resting (PECO=1.94 , DCCO=1.85). Running a two-sample t-test on dive to rest ratios for both species showed that they are not significantly different ($p=0.587$).

Discussion

Tidal Phase and Abundance

Foraging cormorants were only observed during slow current speeds, notably during slack low (n = 13) and slack high (n = 1) (Fig. 1). No cormorants (n = 0) were observed feeding during max flood. These results show that foraging times are dependent on two factors, current speed and water depth. Current speed has an effect on diving behavior because water movements may affect the ability of the diving cormorants to find and catch prey. Faster currents would have greater effects on larger birds like the DCCO because of increased drag force. Cormorants rely on a gliding technique of swimming to conserve energy (Ribak et al., 2005). Increased current speed and thus increased drag would be more energetically taxing on the diver. Thus, foraging is more energetically profitable during slower current speeds, given prey is available at that time.

Currents also play a factor in prey abundance and availability. Incoming flood currents can push fish toward the shore and feeding cormorants. The most foraging cormorants were observed feeding at slow moving flood currents (Fig. 1), which explains that prey is most readily available when currents are slow enough for cormorants to maneuver underwater. Most cormorants were observed feeding shortly after slack low. Water depth also seems to play a factor in the selection of foraging times. Shallower water could be beneficial to divers because prey would be more concentrated in a shallower water column. A higher abundance per unit volume increases the chance of predatory success. Another aspect of a shallow depth is that light will penetrate to a larger proportion of the water column so locating prey becomes easier. A higher abundance coupled with increased visibility would increase foraging efficiency. It seems that a combination of both current speed and tidal height could be playing a factor into how cormorants select foraging times and location.

Comparison of Dive Duration

Our results show that PECOs had a higher mean dive duration than DCCOs (Table 1, Fig. 2). It would be expected that DCCO may have longer mean dive times because they are larger birds. Being a larger bird has a few implications concerning dive physiology. The first is that a larger bird has a larger surface area to volume ratio and thus maintains heat more efficiently than a smaller bird. In a cold ocean, thermoregulation is very important heavily influences dive time if heat is rapidly lost while underwater (Croll and McLaren, 1993). The next is that a larger bird seemingly can store more oxygen, which is important for aerobic diving because it will have more myoglobin storage fibers (Croll et al., 1992). Our results seem to suggest that these physiological advantages of being a larger bird are trivial. Our results can be explained by DCCOs being better foragers and are finding prey more quickly. The same prey was observed for both DCCOs and PECOs (when prey was brought to the surface) on several occasions. Thus, DCCOs shorter mean dive duration can be explained if DCCOs are more efficient foragers because they would return to the surface more quickly after prey is caught in a timelier manner.

Another explanation may be that with larger surface areas and thus more drag, DCCOs are using energy more quickly than smaller PECOs and must return to the surface to rest or intake more oxygen to continue aerobic diving. Metabolic toxins, such as lactate are also a concern if in fact the DCCO is working harder to dive than the PECO because of more drag. Lactate is produced when oxygen is not available and is inhibitory to muscular movement in high concentrations (Brooks, 1985), therefore a period of rest must occur in high concentrations. If DCCOs are reaching an aerobic threshold (Brooks, 1985) faster than PECOs, rest is needed sooner and shorter dive times are a result.

The Pelagic Cormorant is a smaller species than the Double Crested. With smaller beaks, PECOs are able to feed in small crevices that DCCOs do not have access too. If PECOs are using their niche in this environment and feeding in crevices, they may be diving deeper than DCCOs to reach these areas and longer dive times are observed as a result.

Our mean dive time for PECOs, 32.6 ± 14.0 seconds is similar to the result of a previous study of 31.2 ± 11.7 seconds (Manrique Bravo et al., 2005) also conducted in Cattle Pass near Goose Island. However during a different season which suggests that seasonal variance in cormorant diving behavior is small. Our mean dive time for DCCOs, 23.1 ± 8.1 seconds is also comparable to values estimated in previous studies. A mean of 20.3 ± 1.4 seconds was reported for a lab-based study of Double Crested Cormorant dive behaviors (Enstipp et al., 2001).

Dive and Recovery Relationship

Resting times are important to any diving bird in order to restore oxygen, energy or decrease the concentration metabolic toxins such as lactate (Ponganis et al., 1997). Both the Double Crested and the Pelagic Cormorant spend more time diving than resting (Fig. 3). These results indicate that cormorants exhibit a diving technique that employs many dives and then a long resting period to satisfy oxygen or energy debts (Croll et al., 1992). With dive time to recovery time ratios of 1.85 and 1.94 for DCCOs and PECOs respectively, cormorants seem to collect an oxygen debt as more dives are completed and must follow the mechanism presented above to regain oxygen.

The mean dive and recovery duration ratios for PECOs and DCCOs may be explained by each species' (or individual diver's) aerobic dive limit (ADL). This limit is reached when the net production of lactate is positive (Kooyman 1989). Divers can thereafter undergo anaerobic diving, but at a higher energy cost and for much shorter periods than aerobic diving. Most focal birds took flight after completing their dive bouts, so a final rest recovery period was not observed. However, for subjects with high dive to recovery ratios, anaerobic diving could have played a factor in discontinuation of diving and a large energy debt could be present.

There are many opportunities for further studies to be conducted on this subject. For one, data could be collected on where cormorants from Goose Island are flying after their diving bouts and possibly identifying another area where they are feeding or resting. More accurate measurements of final resting period could help determine actual oxygen debts and calculate an accurate recovery rate. Prey analysis would also be useful in order to calculate how many fish need to be consumed to overcome energy use of diving.

References

Croll, D. A., A. J. Gaston, A. E. Burger and D. Konnoff. 1992. Foraging Behavior and Physiological Adaptation for Diving in Thick-Billed Murres. Ecology. **73**: 344-356.

Croll, D. A. and E. McLaren. 1993. Diving metabolism and thermoregulation in common and thick-billed murres. Journal of Comparative Physiology. **163**(2): 160-166.

Enstipp, M. R., R. D. Andrews and D. R. Jones. 2001. The effects of depth on the cardiac and behavioural responses of double crested (*Phalacrocorax auritus*) during voluntary diving. Journal of Experimental Biology. **204**: 4081-4092.

Hobson, K. A. and S. G. Sealy. 1985. Diving rhythms and diurnal roosting times of Pelagic Cormorants. Wilson Bull. 97:1:116-119.

Kooyman, G. L., 1989. Diverse Divers: Physiology and Behavior. Zoophysiology Series, Vol.23.

Manrique Bravo, C. and M. Williams de Castro. 2005. Tidal and inside-season effects of the diving behavior of pelagic cormorants (*Phalacrocorax pelagicus*) at Cattle Point, San Juan Island, WA, USA. Ecologia Aplicada. **4:** 121-125.

Ponganis, P. J., G. L. Kooyman, L. N. Starke, C. A. Kooyman and T. G. Kooyman. 1997. Post-dive blood lactate concentrations in emperor penguins, *Aptenodytes forsteri.* Journal of Experimental Biology. **200**: 1623-1626.

Ribak, G., D. Weihs and Z. Arad. 2005. Submerged swimming of the great cormorant *Phalacrocorax carbo sinensis* is a variant of the burst-and-glide gait. Journal of Experimental Biology. **208**: 3835-3849.

Sapoznikow A. & Quintana F. 2003. Foraging and feeding locations of Imperial cormorants and Rock shag breeding sympatrically in Patagonia, Argentina. Waterbirds. **26**(2): 184-191.

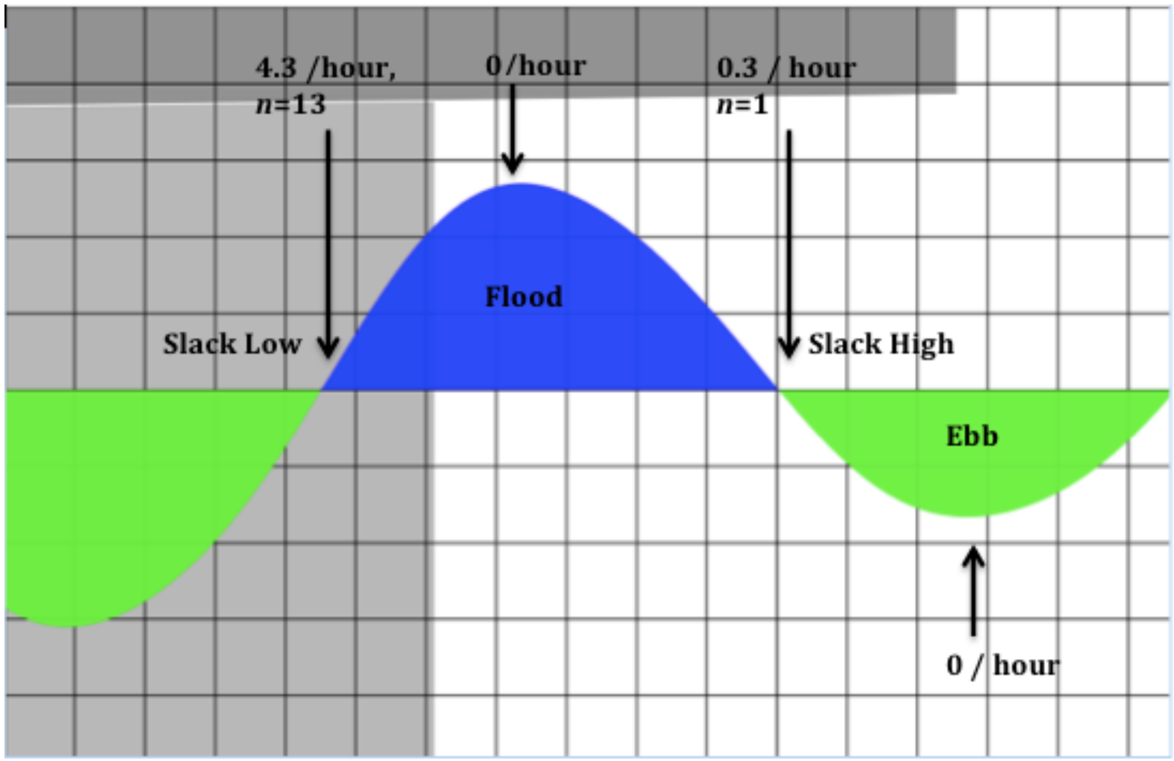

Figure 1. Arbitrary representation of tidal phases of Cattle Pass, San Juan Island, WA. Observations of diving cormorants were made during all tidal phases (Slack flood, max flood, slack ebb, and max ebb). No birds were observed diving during either max flood or ebb, and only a single bird was observed diving during slack ebb. The highest abundance of diving birds was observed during the start of slack flood (*n*=13). Rate of diving birds per hour was calculated for all observation times.

Table 1. Mean and max/min dive durations and rest times of both Pelagic and Double Crested Cormorants. Mean dive duration calculated from DCCO (*n*=68) dives and PECO (*n*=63) dives.

	Pelagic	**Double Crested**
Mean Dive Duration	32.6 ± 14.0 (*n*=68)	23.1 ± 8.1 (*n*=63)
Max. Dive Duration	72.5	50.0
Min. Dive Duration	6.6	9.6
Mean Rest Duration	18.8 ± 9.7	14.7 ± 11.3
Max. Rest Duration	42.5	74.5
Min. Rest Duration	6.2	5.3

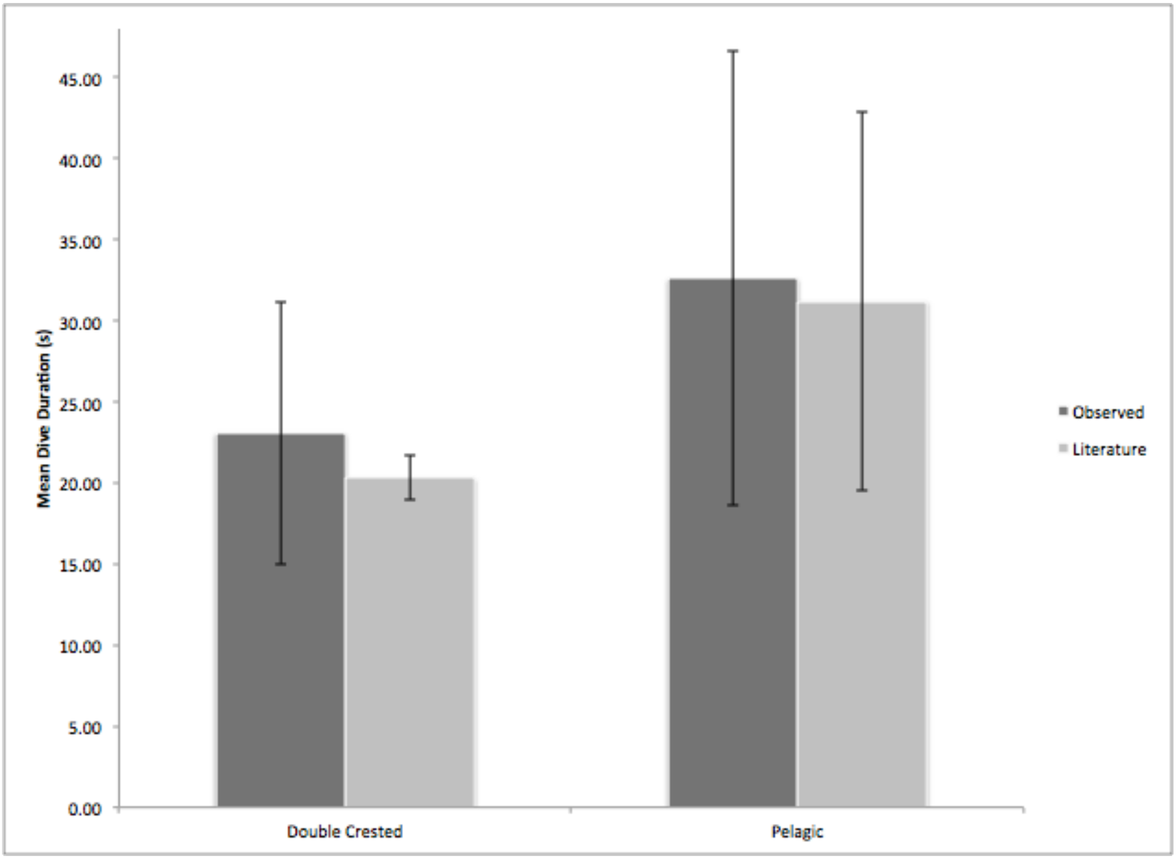

Figure 2. Mean dive duration of both species of cormorant (DCCO and PECO, n=113) compared to mean dive durations observed in previous studies. PECO= 32.6 ± 14.0 , DCCO = 23.1 ± 8.1

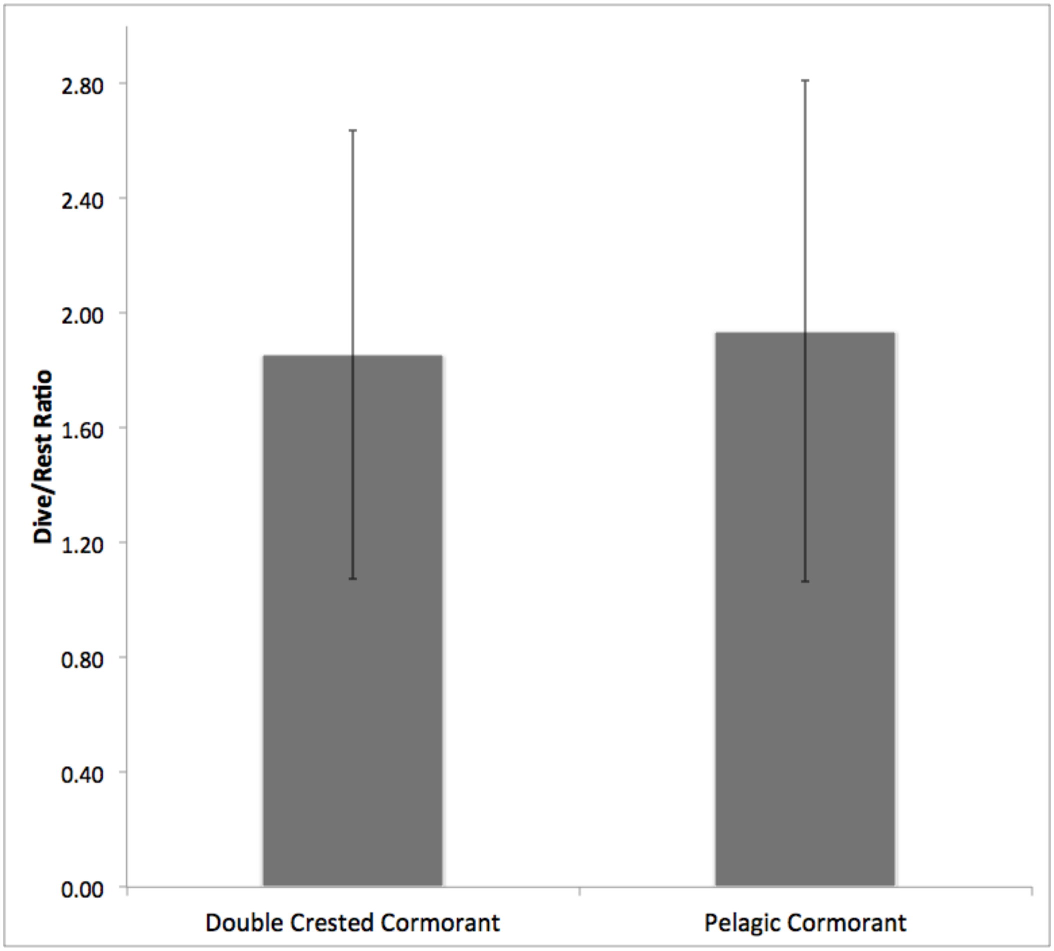

Figure 3. Dive rest ratio calculated for both species of cormorants (DCCO and PECO). Ratios were very similar, 1.85 for DCCO and 1.94 for PECO. Ratios were calculated by dividing each dive duration and recovery time pair, then averaging for both species. A *t*-test was run on both ratios and we found that they are not significantly different ($p<0.05$, $p=0.587$).