Water Clarity and Diving Behavior in Wintering Common Loons

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Abstract.—Studies of the Common Loon (*Gavia immer*) during its breeding season on northern freshwater lakes in North America have suggested that water quality has an influence on breeding and foraging success. Less is known, however, about the effects of water quality on loon behavior during the winter, which is spent in estuarine and marine environments. In this study, we investigated the effects of water clarity and tidal stage on loon diving behavior at seven sites along a Maryland estuary. At each site, the total number of loons observed and mean dive durations of individuals were measured and compared to various measurements of water clarity, including Secchi depth and turbidity, and to tidal stage. Dive durations were positively associated with Secchi depth, which indicates that birds dove for longer periods in areas with higher water clarity. Dives were also longer during low tide in comparison to other tidal stages. No relationship was found between aspects of water clarity and the distribution of wintering loons. *Received 4 September 2005, accepted 25 February 2006.*

Key words.—Common Loon, foraging, non-breeding season, tidal stage, water clarity.

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The Common Loon (*Gavia immer*) is a well-known North American water-bird that breeds primarily on northern freshwater lakes during the summer and migrates to the Atlantic, Pacific, and Gulf coasts where it winters (Kerlinger 1982). Along the Atlantic coast, the Common Loon's wintering grounds range from Newfoundland and Labrador to central Florida, with large populations settling along the coasts of Virginia, the Carolinas, and northern Florida (McIntyre and Barr 1997). Loons are relatively common during the winter in the Chesapeake Bay, where large aggregations of hundreds of loons have been recorded taking advantage of the Bay's populations of fish prey and shelter from offshore waves (McIntyre and Barr 1997). Various studies have examined the feeding ecology of Common Loons during its summer breeding season (e.g., Alvo *et al.* 1988; McIntyre 1988; Alvo and Berrill 1992; Blair 1992; Nocera and Burgess 2002). Much less is known, however, about loon feeding behavior during the winter (McIntyre and Barr 1997).

Foraging behavior in piscivorous birds such as loons can be affected by a variety of factors, including prey density, water depth, and water clarity. While hunting for food, Common Loons can dive for periods surpassing two minutes (Nocera and Burgess 2002) and are known to achieve dive depths of up to 60 meters (Roberts 1932). Because loons must be able to visually spot their prey, foraging success should be greater in clearer, less-turbid water than in water with lower visibility. But water quality might impact loon foraging success in other ways as well, for example, by affecting the health and behavior of the aquatic organisms preyed on by loons. Primary producers such as submerged aquatic vegetation and phytoplankton are directly affected by water clarity and nutrient loads, as these factors determine their photosynthetic efficiency (Mann 2000). Because producers provide habitat and food for a variety of organisms, including those preyed on by diving birds, good water quality is essential to the overall health of any aquatic system.

Increased sediments and nutrients in a body of water can both directly and indirectly increase water color and decrease water clarity. Particulate matter in the water, measured as total suspended solids (TSS), and nutrients, such as dissolved organic carbon (DOC), can increase turbidity and water color while also fuelling plankton with energy, which can lead to algal blooms that further diminish water clarity (Wissel *et al.* 2003). A variety of abiotic factors, including DOC and TSS, as well as biotic factors, such as phytoplankton abundance, contribute to decreases in overall water clarity. Turbidity, or the cloudiness of water, provides a good assessment of clarity by measuring the scattering of light by abiotic and biotic particles in the water. Increased particulate matter will increase turbidity and decrease light transmission (Gadomski and Parsley 2005). Secchi depth provides a more comprehensive assessment of overall clarity by measuring visibility in water, which is influenced by both water color and particulate matter (Davies-Colley and Smith 2001; Wissel *et al.* 2003).

Studies of Common Loons during the summer have shown that breeding and foraging behaviors in this species are influenced by water quality. For example, Alvo *et al.* (1988) found that loon breeding success is lower on lakes with more water color and that loons avoid breeding in small, brown, low-alkalinity lakes. Likewise, Blair (1992) found that water clarity, measured as Secchi depth and water color, is an important secondary factor determining lake selection by breeding loons in New Hampshire. Primary determining factors were physical parameters, including the area, depth, and surface temperature of lakes during the breeding season. Breeding loons prefer to inhabit less productive lakes with high surface water temperatures and relatively large surface areas and depths (Blair 1992; McIntyre and Barr 1997).

Although much is known about how environmental factors affect loons on their breeding range, relatively little is known about the effects of water quality on loon behavior during the winter. In this study we observed the presence and absence of loons in relation to the physical and chemical water characteristics of several sites along a Maryland estuary off the Chesapeake Bay, and measured the durations of foraging dives by loons at each site. The quality of many estuarine habitats in the Common Loon winter range are facing declines due to human activities, particularly in the Chesapeake watershed (e.g., Erwin *et al.* 1993; Cooper, 1995). Understanding the effects of these declines in water quality on loons and other migratory water-birds that visit these areas is becoming increasingly important and should be a crucial component of our efforts to conserve these species.

Methods

Seven locations along the St. Mary's River, a Maryland estuary near the confluence of the Potomac River and Chesapeake Bay, were selected as study sites based on the locations of water quality sampling data collected from 1999 to 2005 by the St. Mary's River Project (SM-RP) at St. Mary's College of Maryland, St. Mary's City, MD. Sites known to have poor clarity were chosen as well as sites known to be relatively less turbid. This contrast in water quality among sites allowed for comparisons of site preferences and diving behavior with chemical and physical estuarine factors. The seven study sites (shown in Fig. 1) were at Tippity Witchity (T02), Church Point (T04), Carthagena Creek (T08), St. George's Creek (T09), St. Inigoes Creek (T10), Sage Point (854), and Piney Point (855). Four of the sites (T02, T04, 854, and 855) were in the main stem of either the St. Mary's or Potomac rivers while three sites (T08, T09, and T10) were in creeks that empty into the St. Mary's River.

Land-accessible sites were located near each selected tidal sampling site as vantage points from which to observe loons using 8 × 40 binoculars or a 20-60× spotting scope. Each site was visited twice a month from 2 November 2004 to 4 March 2005. Common Loons arrived on the St. Mary's River at the beginning of November and began migrating back to their breeding grounds between April and early June (McIntyre and Barr 1997). Observation times occurred between 08:00 h -16:00 h. No correlation has been observed in previous studies between diurnal time of day and the site preferences or foraging behaviors of Common Loons (Ford and Gieg 1995; Holm and Burger 2002).

During each observation session, loons were observed for exactly one hour during which the total number of loons present, the dive durations of individuals,

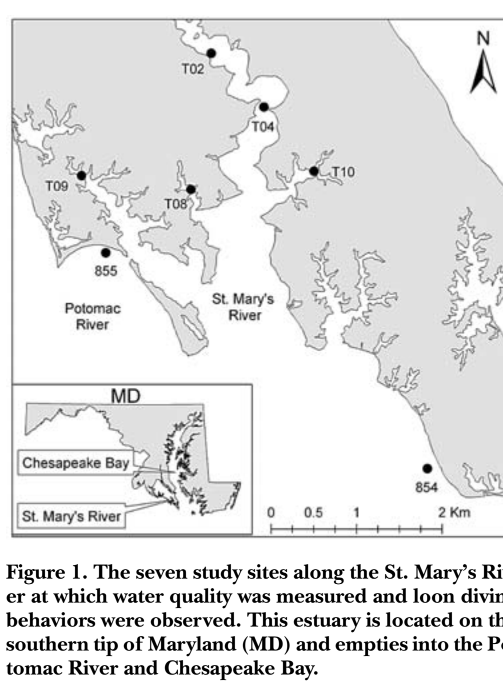

Figure 1. The seven study sites along the St. Mary's River at which water quality was measured and loon diving behaviors were observed. This estuary is located on the southern tip of Maryland (MD) and empties into the Potomac River and Chesapeake Bay.

and tidal stage were recorded. Duration was measured for each observed dive using a stop watch. If more than one loon was present at a site, one individual was randomly selected for measuring dive durations. Loons were not individually marked; however, dives that occurred while nearby loons were also underwater were not measured to prevent the possibility of misidentifying individuals. We defined the beginning of a dive as the moment the loon was fully submerged (so as not to be confused with their "peering" behavior), and defined the end of a dive as the moment the loon emerged from the water.

Water quality data was obtained for each site from the SMRP. These data included depth profiles of water chemistry and filtered analyses of surface samples, focusing primarily on water clarity and color. Depth profiles at one meter increments (0, 1, 2, and 3 m) were recorded for turbidity (nephelometric turbidity units, NTU) at each site using a YSI sonde 6600 (Yellow Springs Instruments, Yellow Springs, Ohio). Turbidity values at depths of 2 and 3 m were not obtained for all sites because not all were sufficiently deep. Surface water samples were also taken and filtered using 25 mm glass fiber filters, from which total suspended solids (TSS) on the filter and dissolved organic carbon (DOC) in the filtrate were analyzed by the Chesapeake Biological Laboratory, University of Maryland Center for Environmental Science. The SMRP also measured Secchi depths for each site. A Secchi disk was lowered in the water column beyond the depth at which its black and white pattern could be seen, then was slowly raised until the pattern could be distinguished. Secchi depth was measured as the distance from the surface of the water to the deepest point at which the Secchi disk pattern could be distinguished.

Single factor ANOVAs were performed to analyze whether aspects of water clarity and loon behavior differed among the seven sites. The influence of site location on mean TSS, DOC, Secchi depth, average subsurface turbidity, number of loons observed, and loon dive duration was determined. Single factor ANOVAs were also performed to analyze the effect of tidal stage on number of loons observed and on average dive duration. Post-hoc Tukey tests were used to compare values between individual sites. After determining which water clarity parameters differed significantly across sites, regression analyses were used to test for relationships between water clarity parameters and loon diving behavior. These tests were also used to evaluate relationships between dive durations and tidal stage. Measurements of water clarity and dive durations were compared to mean water depth measured at each sampling site to see if depth had an influence on any of these variables. All statistical analyses were done using SPSS (Version 11.0.2).

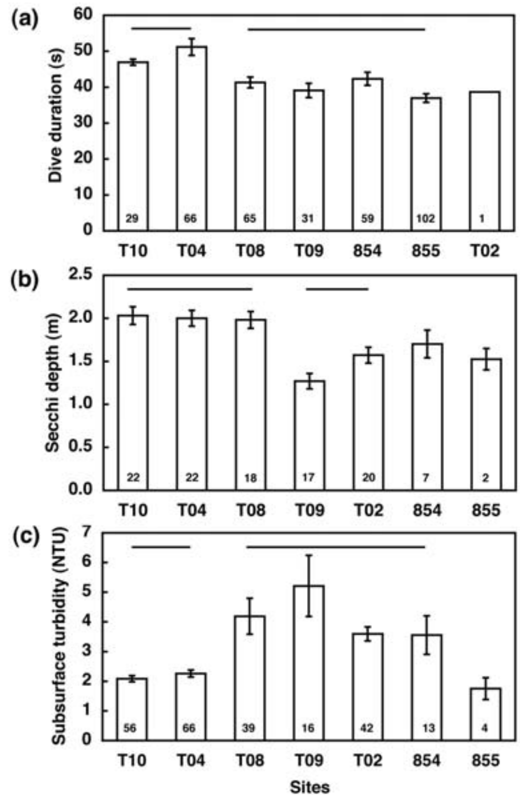

Figure 2. Mean (± SE) measurements of (a) loon dive duration, (b) Secchi depth, and (c) subsurface turbidity at seven sites on the St. Mary's River, MD. All three variables differed significantly among study sites (single factor ANOVAs, P < 0.001). Sample sizes (N) are given at the base of each column. Subsurface turbidity is the average of turbidity measures taken at 1, 2, and 3m depths. Sites with similar means, as determined by Tukey post-hoc tests, are joined with solid horizontal lines. Loons were observed from November 2004 through February 2005; Secchi depths and turbidity measurements were taken from November 1999 through February 2005.

RESULTS

Differences in Diving Behavior and Water Clarity Across Sites

Average loon dive durations were significantly influenced by site location (Fig. 2a; single factor ANOVA; $F_{6,346} = 8.35$; $P < 0.001$). Loons dove for consistently longer intervals at some sites than at others. The number of loons observed at a site varied across locations and in visits to the same location at different times; however, we found no consistent differences in the number of loons foraging at each study site ($F_{6,42} = 1.88$; $P = 0.11$).

Analyses of the four water clarity parameters (TSS, DOC, Secchi depth, and turbidity) revealed that only Secchi depth and turbidity below the surface (at depths of 1, 2, and 3 m) varied significantly among the seven study sites (Fig. 2b, c; Secchi depth: $F_{6,101}$ =

7.97, P < 0.001; average subsurface turbidity: $F_{6,229}$ = 8.74, P < 0.001). Measurements of TSS, DOC, and surface (0 m) turbidity did not differ significantly among sites in our analysis (P > 0.05) and so were not analyzed further. Because turbidity values at each depth (1, 2, and 3 m) varied significantly among sites (p < 0.005 in ANOVAs) and were strongly correlated with each other (r = 0.82 - 0.99 in two tailed Pearson correlations), we combined these measurements and used average subsurface turbidity in all our analyses (Fig. 2c). Post hoc tests showed that significant differences in Secchi depth, average subsurface turbidity, and dive durations existed between a number of sites (Fig. 2a-c).

A weak negative relationship was found across sites between average Secchi depth and average subsurface turbidity (Pearson correlation, two tailed, r = -0.48, N = 7, P = 0.28). Depths varied across sites from 1- 8 m, but depth had no significant relationship to measures of Secchi depth (P = 0.44, r^2 = 0.13) or average subsurface turbidity (P = 0.99, r^2 = 0.00).

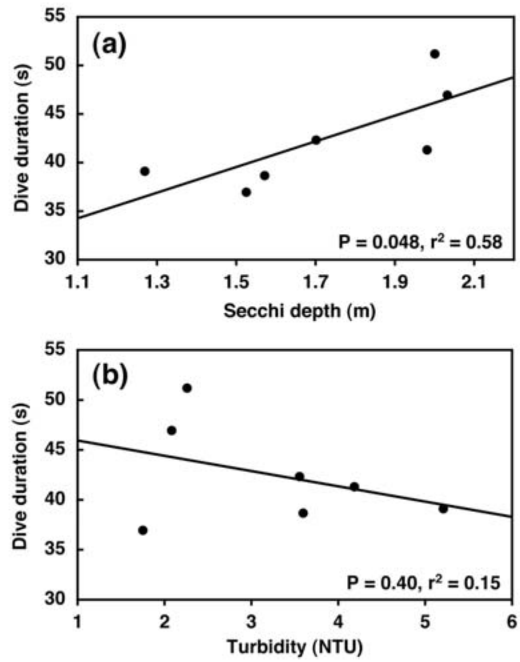

Figure 3. Mean loon dive durations at each study site in comparison to (a) mean Secchi depth and (b) mean subsurface turbidity.

Relationships Between Water Clarity and Loon Diving Behavior

Loon dive duration appeared to be strongly related to Secchi depth. Sites with relatively high mean Secchi depths exhibited significantly longer average dive durations by loons (Fig. 3a; F = 6.82, N = 7, P = 0.048, r^2 = 0.58). Mean dive duration was not significantly associated with average subsurface turbidity (F = 0.86, N = 7, P = 0.40, r^2 = 0.15), but these values had a negative relationship (Fig. 3b). Mean dive duration was also not significantly related to the depth at each site (F = 4.18, N = 7, P = 0.10, r^2 = 0.46).

Tidal Stage and Loon Diving Behavior

Single factor ANOVA and post hoc tests showed that tidal stage had a significant effect on loon dive durations across sites, such that loons dove for significantly longer intervals during low tides than during flood (i.e., incoming) tides (Fig. 4, single factor ANOVA, $F_{3,349}$ = 5.94, P < 0.001). Tidal stage did not appear to significantly affect the total number of loons observed at each study site (P = 0.97).

DISCUSSION

In a study of Common Loon diving behavior during the breeding season, Nocera

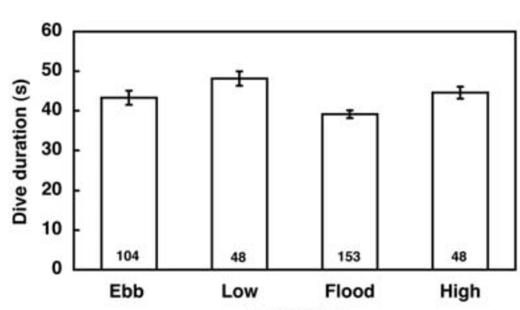

Figure 4. Mean (± SE) loon dive durations during different tidal stages across the seven study sites. Sample sizes (N) are given at the base of each column. Mean dive durations at low tide and flood tide were significantly different in Tukey post-hoc tests (P = 0.001).

and Burgess (2002) found that the amount of time devoted to underwater foraging by loons was not affected by variation in the environment (e.g., water color, pH). In contrast to those results, we found that dive times in an estuary during the winter were strongly influenced by aspects of water clarity and tidal stage. Longer dive durations occurred in areas with greater Secchi depths, suggesting that loons tend to dive for longer intervals in areas of higher water clarity. Nearly 58% of the variance in mean dive duration across sites was explained by differences in visibility, measured as Secchi depth, and none of our measures of water clarity appeared to be influenced by depth.

Dive durations were also significantly longer during low tide in comparison to flood tide, which is consistent with previous evidence that wintering loons alter their foraging behaviors depending on tidal stage (McIntyre 1978; Holm and Burger 2002; but see Ford and Gieg 1995). The overall mean dive duration for loons in our study (42.3 s, SE = 0.76 s, N = 353) was similar to mean durations measured in previous studies of loons on freshwater lakes (42.9 s by McIntyre 1978, 42.6 s by Parker 1985, 45.8 s by Alvo and Berrill 1992, 39.7 s by Nocera and Burgess 2002) and wintering loons in coastal areas (39.5 s by McIntyre 1978). These previous measurements fall within the range of means found in our study across different sites (36.9 s - 51.2 s, Fig 2a) and during different tidal stages (39.1 s - 48.2 s, Fig 4).

Dive durations in the St. Mary's River correlated most strongly with Secchi depth, which among our measures was probably the most complete indicator of overall water clarity. Rather than measuring one specific constituent of water clarity, as do TSS and DOC, Secchi depth is influenced by a variety of factors including particulate matter and water color caused by dissolved matter (Davies-Colley and Smith 2001). Turbidity may have been only moderately correlated with dive durations because it measures only particulate matter in water and thus does not measure actual water clarity as comprehensively as does Secchi depth.

Loons are visual predators (McIntyre and Barr 1997), so a loon's ability to detect distant prey is probably greatly enhanced in clear water relative to water with lower visibility. Loons often peer down to spot prey before diving, and clearer water may allow loons to pursue prey that would not be detected in more colored, turbid areas. Chasing prey that are deeper or farther away would result in longer dives. Loons are known to dive deeper in clearer water (Roberts 1932; McIntyre and Barr 1997), and this agrees with studies of other visual piscivorous birds showing that foraging success is greatly enhanced by increased water clarity (e.g., Brenninkmeijer *et al.* 2002).

A relationship between dive duration and water clarity could also result from differences in the availability and distribution of prey. For example, loons might focus on different prey species in areas with different water clarity, and these prey might require different pursuit times. Bottom-dwelling crustaceans make up a large part of a loon's diet, especially in water with low visibility (Barr 1996), and capturing these organisms probably requires briefer dives than does the pursuit of faster-swimming fish. It is also possible that differences in dive durations reflect differences in the locations of prey in the water column. Phytoplankton need sufficient light for photosynthesis and therefore might occupy higher layers of the water column in areas of low water clarity (Davies-Colley and Smith 2001). Planktivorous fish in these areas might aggregate in upper strata to forage, allowing loons to make shorter dives to pursue them.

Loons ingest most of their prey underwater (Barr 1996; McIntyre and Barr 1997), so we were unable to distinguish between successful and unsuccessful dives. However, if water clarity has an effect on foraging success, dive durations might reflect differences in the foraging schedules used by loons in patches of different quality. Rather than investing energy and time in long dives in turbid areas where prey are difficult to detect, perhaps loons instead return to the surface earlier to begin searching for prey in other areas nearby. Thompson and Fedak (2001) found that seals employ such a conditional strategy while foraging by assessing the quality of different patches based on prey encounter rate and then using shallower (and presumably shorter) dives where prey are detected less often. Longer dives by loons could also result from high capture rates simply because ingesting prey requires time during a dive. More time spent consuming prey in an area could have resulted in longer average dive durations.

While several studies have found a relationship between water quality and habitat selection by loons on their breeding range (e.g., Alvo *et al.* 1988; Blair 1992), our study found no apparent relationship between water clarity and the total number of loons observed at each site. Although our sample of seven sites may have been insufficient to adequately test for habitat preferences, our results could reflect differences between the breeding and non-breeding seasons in the habitat choices made by loons. Alvo *et al.* (1988) found a negative relationship between loon breeding success and water color during the summer, and that loons avoid breeding on small lakes with poor water quality. These preferences may at least partly reflect the water chemistry preferences of chicks rather than just adults, since alkalinity and water color may have an effect on offspring survival (Alvo and Berrill 1992). Loons are not necessarily influenced by the preferences of offspring during the winter and therefore might be less discriminating about water quality while selecting winter habitats (Nocera and Burgess 2002).

Our finding that loons dove for longer intervals during low tides than at other tidal stages is probably not explained by differences in depth, as birds would be expected to dive for shorter periods in shallower water. Previous research has shown similar relationships between foraging activity in diving birds and tidal stage. McIntyre (1978), in a study of wintering loons off Assateague Island, Virginia, observed an increase in loon feeding rates as well as movements into shallower water during ebb (i.e., receding) tides in comparison to other tidal stages. Likewise, Holm and Burger (2002) found that a variety of piscivorous diving birds, including loons, prefer to forage in moderate tidal currents, though they avoid areas with strong currents and turbulence. In wintering terns, Brenninkmeijer *et al.* (2002) observed the greatest prey consumption during ebb and low tides and lower consumption rates during high tide. We observed a larger number of loons foraging during ebb tides than during other stages, although this trend was not significant. Previous findings by Daub (1989) and Ford and Gieg (1995) suggesting no relationship between loon foraging behavior and tidal cycle may have been due to the fact that both studies were conducted in an area (Weekapaug, Rhode Island) with relatively small tidal changes (Ford and Gieg 1995).

McIntyre (1978) proposed that loons in tidal habitats might prefer foraging during ebb tides to take advantage of the increased concentrations of prey as inshore areas become shallower. Loons might also feed on predatory fish as these fish move inshore to feed on prey that have become vulnerable from the receding tide (McIntyre 1978). If loons are more successful at spotting and capturing prey during lower tides, they might exhibit longer dives during these periods for some of the reasons mentioned above. Future studies may wish to investigate this potential relationship between dive duration and foraging success.

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