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AMERICAN WHITE PELICAN SOARING FLIGHT TIMES AND ALTITUDES RELATIVE TO CHANGES IN THERMAL DEPTH AND INTENSITY

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Abstract. We compared American White Pelican (*Pelecanus erythrorhynchos*) soaring flight times and altitudes to model-produced estimates of thermal depth and intensity. These data showed that pelican soaring flight was confined to the thermal layer, and that the vertical extent of the soaring flight envelope increased with increases in thermal depth. Pelicans soaring cross-country between foraging and breeding sites flew mainly within the middle of the thermal layer, regardless of its depth. In contrast, pelicans engaged in wandering flight near foraging sites typically confined their flight to the lower thermal layer. Pelicans soaring cross-country likely flew higher in the thermal layer to maximize cross-country soaring performance, while pelicans soaring locally presumably flew lower because additional altitude was unneeded for gliding short distances. An analysis of pelican flight times relative to model-produced estimates of thermal intensity suggested that pelicans began soaring as soon as sufficiently strong thermals developed daily.

Key words: American White Pelican, avian soaring performance, cross-country soaring, flight altitudes, flight times, Pelecanus erythrorhynchos, *thermals.*

Tiempo y Altitud del Vuelo Planeado de *Pelecanus erythrorhynchos* con Relación a Cambios en Profundidad e Intensidad de las Corrientes Térmicas

Resumen. Comparamos el tiempo y la intensidad del vuelo planeado del pelícano *Pelecanus erythrorhynchos* con estimaciones modeladas de la profundidad e intensidad de las corrientes térmicas. Estos datos mostraron que el planeo de los pelícanos estuvo confinado a la capa térmica y que la extensión vertical del área de planeo incrementó con incrementos en la profundidad de la corriente térmica. Los pelícanos que planearon a campo traviesa entre los sitios de alimentación y cría volaron principalmente en el medio de la capa térmica, independientemente de su profundidad. En contraste, los pelícanos que vagaron cerca de los sitios de alimentación típicamente restringieron sus vuelos a la parte inferior de la capa térmica. Los pelícanos que planearon a campo traviesa probablemente volaron más alto en la capa térmica para maximizar el desempeño del planeo, mientras que los que planearon a nivel local presumiblemente volaron más bajo porque no necesitaron mayor altitud para planear por distancias cortas. Un análisis del tiempo de vuelo de los pelícanos con relación a las estimaciones modeladas de intensidad de las corrientes térmicas sugirió que los pelícanos comenzaron a planear diariamente tan pronto como aparecieron corrientes térmicas suficientemente fuertes.

Pennycuick (1975) defined soaring as any flight technique where energy is extracted from atmospheric motions and converted to bird potential or kinetic energy. The intimate relationship between avian cross-country soaring flight and thermal development and evolution is well documented. Pennycuick (1972), Welch (1987), and Leshem and Yom-Tov (1996) have observed storks, eagles, hawks, and vultures undertaking long-distance migratory and cross-country flights by soaring in thermal updrafts. Moreover, Kerlinger and Gauthreaux (1985) observed that hawk migration began when conditions favored thermal development, and noted that flight altitude increased in conditions that are expected to increase thermal depth (i.e., the maximum altitude to which a thermal extends). In each of these studies, birds were observed gliding (i.e., flying without flapping) in circles in thermal updrafts to gain altitude, and gliding in relatively straight lines between thermals, typically losing altitude during the interthermal glide. The primary objective of birds in this flight mode is to move from one location to another. Thus, we define avian cross-country soaring performance as the rate at which a bird travels cross-country. Birds in this flight mode can optimize this performance by minimizing their cross-country flight times.

Soaring birds help maximize their climb rates within thermal updrafts by gliding in circles with wings outstretched (Kerlinger 1989). This behavior helps minimize the time spent within a thermal, and hence in-

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creases the cross-country flight speed of a bird (Pennycuick 1975). Analyses of thermal intensity (i.e., magnitude of vertical air motions within a thermal updraft) indicate that the strongest lift typically occurs within the middle levels of the thermals (Kaimal et al. 1976). Thus, soaring birds can increase their cross-country flight speed by soaring primarily in the altitude range where the thermal updrafts are strongest, the middle of the thermal layer. When a bird's interthermal glide angle is too poor to reach the next thermal before leaving this height range, it must use a greater fraction of the thermal layer or resort to flapping. Thus, a poor glider would need to stay in each thermal longer than would otherwise be optimum. Moreover, because birds soaring cross-country typically lose altitude during interthermal glides (Pennycuick 1972, Tucker 1988), birds that climb high within thermal updrafts increase the probability that they can glide the entire distance between thermal updrafts. Thermal depth and intensity varies diurnally, however, in response to changes in the heating of the earth's surface and the stability of the atmosphere (Young 1988). The primary goal of this study was to explore how American White Pelican (*Pelecanus erythrorhynchos*) soaring flight times and altitudes vary with changes in thermal depth and intensity.

METHODS

STUDY AREA

A field study was conducted in the Fallon, Nevada area (39°25′N, 118°41′W) during June and July 1997. Flight altitude data were gathered as pelicans flew among a breeding colony on Anaho Island, Pyramid Lake, and several foraging sites located 100–150 km to the south and east of this colony (see Fig. 1 in Shannon et al. 2002). We assumed birds optimized cross-country soaring performance while traveling among resource areas, because of the extended distances between these sites. The terrain within the study area consists of basins at about 1200 m elevation separated by mountains up to about 2000 m elevation. The breeding and foraging sites are located in these basins, and birds flying among these sites often crossed the mountains. Although water is plentiful at the foraging and breeding sites, the study area as a whole is arid, with abundant sunshine typical during the summer months. These conditions favor the development of strong thermals, and hence deep thermal layers.

DATA COLLECTION

We attached satellite telemetry platform transmitter terminals (PTTs) equipped with pressure sensors to 10 American White Pelicans to monitor bird flight altitudes. These birds were caught by hand at the breeding colony on Anaho Island and by using a rocket net at a foraging site in Stillwater National Wildlife Refuge. Additional description of the transmitters and attachment harnesses is provided in Shannon et al. (2002). Altitude data were updated every 60 sec, providing a detailed description of flight altitudes for comparison to the evolving thermal depth. Shannon et al. (2002) showed that the uncertainty in transmitter-derived altitude measurements is small. Assuming zero bias, the SD in the differences between transmitter-derived altitudes and readings from a control altimeter was approximately 15 m. This uncertainty is much less than the measured flight altitudes and estimated thermal depths observed during this study.

Two 2-person teams collected daily flight altitude and behavioral data from 6 June to 7 July. The first daily objective of each team was to identify the time at which pelicans began soaring. Each team accomplished this task by driving to a breeding or foraging site prior to thermal initiation, and noting the time at which the first pelican completed one circle with fixed wings. Variations of this criterion requiring more pelicans and more circles yielded similar times. After obtaining first soaring data, each team tracked a radio-marked bird using either a car or a Cessna 172 aircraft. Although tracking could be accomplished from the ground, sightings were often difficult to obtain because of the high altitudes at which these birds frequently flew. For this reason, the majority of the flight altitude and behavioral data were obtained during about 80 hr of tracking from the aircraft. These observations were critical for verifying that radio-marked birds were indeed soaring during periods when we were relating flight to meteorological conditions.

MODEL ESTIMATES

Although continuous regional measurements of thermal depth would be most useful for comparison to flight altitudes, such data are not generally available because of the dense observational network required. As a result, a simple numerical model was developed to diagnose changes in thermal depth and intensity, given the available meteorological data within the study area. Atmospheric sounding (i.e., weather balloons) and surface weather observations were obtained from Naval Air Station Fallon (along a flight path of these birds) to operate this model. The model diagnoses thermal depth by estimating the buoyancy of air near the ground and determining the maximum altitude to which this air can rise before becoming less buoyant than the surroundings. A detailed description of this model and a statistical verification of its accuracy are given in Shannon et al. (2002). Model estimates of thermal depth (abbreviated as z_i) and intensity reported in this paper are means ± SD.

RESULTS

SOARING FLIGHT BEHAVIOR

Observations of pelicans during this study indicated that the birds alternately soar in thermals and glide when flying cross country. Flock sizes ranged from a few birds to several hundred birds, with flocks generally increasing in size the closer they were to the breeding colony. The radio-marked pelicans were observed carefully from the aircraft to determine if the PTTs influenced their behavior or flight altitude. We concluded that the instrumentation had little influence on these birds because their thermal climb rates and interthermal glide speeds were not visibly different from those of surrounding birds. Given these observations, these data were deemed suitable for comparison with modeled estimates of thermal depth and intensity.

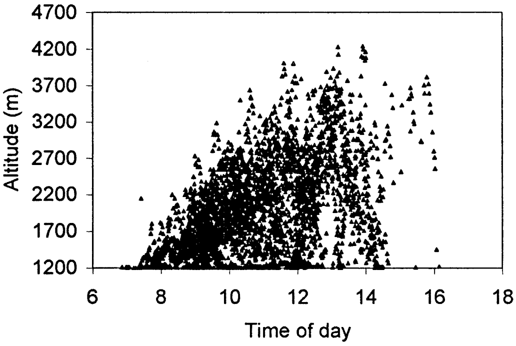

FIGURE 1. Temporal distribution of all flight altitudes recorded from 10 American White Pelicans near Fallon, Nevada.

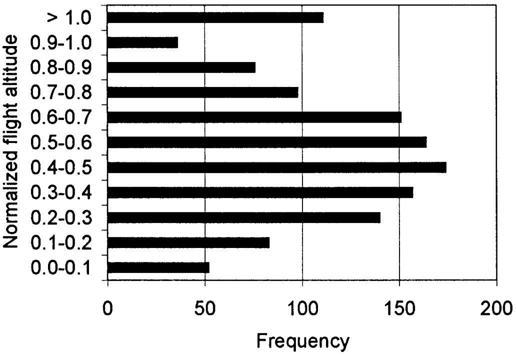

FIGURE 2. Combined distribution of flight altitudes, normalized by model-derived estimates of thermal depth (z_i), for all cross-country flights ($n = 25$) of 10 American White Pelicans.

SOARING FLIGHT ALTITUDES

Figure 1 illustrates the temporal distribution of all flight altitudes measured during this study. The highest flight altitude was 4240 m, approximately 3040 m above the basins. These data demonstrate that the vertical extent of the pelican flight envelope can vary significantly on relatively short time scales, and that the depth of this envelope typically increases throughout the day, consistent with diurnal changes in thermal depth.

The majority of the flight altitude data gathered during this study was obtained while pelicans flew cross-country between the foraging and breeding sites. The remaining data, however, were obtained from birds that engaged in local flights near a foraging site. We used a 10-km range criterion to differentiate between these two flight modes. A large proportion of the local flight data was confined to the lower thermal layer, with 57% of the data points occurring between 0.1 and $0.4z_i$ (Fig. 6 in Shannon et al. 2002). Given that nonbreeding pelicans have less motivation to fly cross country than their breeding counterparts, the low altitudes of these flights, in comparison with the cross-country flight data reported below, could be explained by these birds not needing to optimize their cross-country soaring performance. Two of the three birds that engaged in local flights typically did not fly cross country to the breeding colony or other foraging sites, suggesting that these birds were indeed nonbreeders. One bird that engaged in local flight, however, often flew cross country between foraging and breeding sites. Meteorological conditions were suitable for thermal cross-country soaring on all of these days, as evidenced by other birds completing cross-country flights.

In contrast to the local flights, birds flying cross country always flew from one foraging or breeding site to another. Also, while local flight data were only from birds flying over a basin, cross-country flight data were compiled from birds flying over basins and mountains. Given that thermal depth and intensity often varies between the basins and surrounding mountains, the model used to estimate these parameter values was configured to provide them for both elevation regimes (Shannon et al. 2002). Approximately 71% of the cross-country data points fell between $0.2z_i$ and $0.8z_i$, indicating that the majority of cross-country soaring flight is confined to the middle of the thermal layer (Fig. 2), consistent with the theoretical expectations of thermal cross-country soaring flight introduced above. These data suggest that the birds did indeed attempt to maximize their cross-country soaring performance. Birds using thermals as their primary source of lift should be unable to soar above the thermal layer; the data points in excess of $1.0z_i$ are attributed to model error in diagnosing this depth (Shannon et al. 2002). A comparison of the maximum measured flight altitude each day to the modeled thermal depth at the times of these measurements demonstrates further how flight altitudes are influenced by thermal depth ($r^2 = 0.68$, $n = 17$). Thus, the altitude envelope of this flight mode is predictable when estimates of the thermal depth are available.

SOARING FLIGHT TIMES

We compared the minimum sink speed of a pelican circling in a thermal with modeled estimates of thermal intensity to determine if pelican soaring commenced as soon as thermals capable of supporting soaring developed daily. This sink rate is determined from a glide polar, which is a plot of the sink rate of a gliding bird relative to the bird's forward flight speed in straight flight. Pennycuick (1989) showed that the glide polar for a species can be estimated using typical values of its weight, wingspan, and wing area. Using the computer program he developed to accompany Pennycuick (1989), Pennycuick (pers. comm.) estimated the minimum sink rate and the corresponding forward flight speed of an American White Pelican in straight gliding flight near sea level as 0.61 m sec^{-1} and 10.2 m sec^{-1}, respectively, based upon our measurements of captured birds (weight = 5.1 kg, wingspan = 2.5 m, wing area = 0.67 m^2) and assuming representative values for the aerodynamic drag coefficients (induced drag factor = 1.1, body drag coefficient = 0.1). Readers are referred to Pennycuick (1975, 1998) for discussion on the uncertainties associated with these measurements and assumptions, and how these uncertainties can influence predicted values of the sink rate and forward flight speed. Adjusting these speeds for atmospheric density effects using equation (4) in Pennycuick (1971) leads to a sink rate and forward flight speed at an altitude of 1200 m of approximately 0.65 m sec^{-1} and 10.8 m sec^{-1}. Observations of pelicans soaring in thermals during this study indicated that they banked at an angle of approximately 25°, consistent with observations of other soaring species in other studies. Accounting for this bank angle via equations (13) and (14) in Pennycuick (1971) produced a sink rate and forward flight speed of 0.75 m sec^{-1} and 11.3 m sec^{-1}. Similarly, the turn radius, approximated based on equation (8) in Pennycuick (1971), is 28 m.

The intensity of thermal updrafts is related to a convective velocity scale that captures the effects of solar heating and thermal depth (Greenhut and Khalsa 1982). Thermal depth and the convective velocity scale are available from the numerical model (Shannon et al. 2002). During this study, the mean modeled thermal depth at first soaring time was 142 ± 117 m and the mean convective velocity scale was estimated as 0.63 ± 0.33 m sec^{-1}. Birds observed at first soaring typically flapped to about 40 m above the ground, or approximately $0.3z_i$, before fixing their wings and attempting to soar. Greenhut and Khalsa (1982) showed that the thermal intensity at $0.3z_i$ is 1.13 times the convective velocity scale. Thus, the mean thermal intensity at first soaring can be approximated as 0.71 m sec^{-1}. Likewise, Greenhut and Khalsa (1982) found that the diameter of thermal updrafts may be estimated as 0.12 times the thermal depth, z_i. Halving the resulting diameter gives the radius of an average thermal at first soaring as approximately 9 m. The modeled thermal intensity (0.71 m sec^{-1}) and radius (9 m) are thus slightly less than that required to support soaring flight, as determined from the minimum sink rate (0.75 m sec^{-1}) and corresponding turning radius (28 m) for a pelican. Although the modeled thermal radius is less than that needed to support soaring flight, the modeled estimate represents only the average thermal in this environment. Therefore, these results suggest that pelicans were likely selecting only the strongest and widest thermals at the time of daily thermal initiation, and thus are attempting to soar cross country as soon as conditions permit. Observations of soaring pelicans near the times of first soaring support this hypothesis. Pelicans typically flapped to climatologically favored locations where the first thermals developed daily (e.g., over a dirt road or field) before attempting to soar, and typically climbed slowly within these thermals, suggesting that these thermals were just strong enough to support this flight.

DISCUSSION

Because the flight times and altitudes presented above were drawn from thermal cross-country soaring, they do not apply when precipitation disrupts the thermal layer. Similarly, these results do not apply to birds using other sources of lift, such as that provided by airflow over a ridge or mountains, or that associated with weather fronts. In addition to these weather limitations, bird behaviors, such as flapping, also affect the applicability of these results. Moreover, birds searching for food on the ground or maintaining a home range often do not need to optimize cross-country soaring performance. Results from this study are likely applicable, however, to other species engaged in thermal cross-country soaring. Such flights may include extended foraging or migratory flights (Pennycuick 1972, Spaar and Bruderer 1996). Given the success of meteorological models in forecasting diurnal and day-to-day changes in the thermal layer (e.g., Sun and Ogura 1980), these results suggest that such models could be used to forecast the times and altitudes of thermal cross-country soaring flight. Such forecasts potentially could be used to better plan aircraft flight routes, and therefore reduce the threat of bird-aircraft collisions. These results also underscore a potential limitation of ground-based bird counts, demonstrating that birds soaring cross country can fly at exceedingly high altitudes, making it difficult for ground-based observers to monitor their passage (Kerlinger 1989).

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