and the results were verified by spectographic analyses of duplicate aliquots. Strontium-90 was separated from calcium by precipitation prior to counting in a low-background counter. The age of the clams was determined by the annual ring method (*7*). Clams may live 30 or more years, but none of those used in the study had lived in the river prior to 1943. In addition, clams within a given age distribution were selected in order to minimize the effects of radioactive decay and variations in specific activity of the water.

The strontium content of 190 shells representing 15 species ranged from 150 to 550 parts per million and varied with species, age of individuals within a species, and shell growth rate (*8*). The average concentration factor (ratio of strontium per gram of shell to strontium per milliliter of water) for strontium in shells from the Clinch River immediately downstream from White Oak Creek was 4.8 × 10^3 and that for Sr^{90}, based on monitoring data for water (*9*), was 6.5 × 10^3. This agreement is good in view of the analytical difficulties in determining low concentrations of Sr^{90} in water. The concentration factors show that clams are sensitive indicators of Sr^{90}, and that because of the observed differences in strontium concentrations, specific activities in clam shells could be used as quantitative indicators of Sr^{90} behavior.

The behavior of Sr^{90} in the Clinch and Tennessee rivers was inferred by comparing the specific activity of Sr^{90} in clam shells from downstream locations with that of the samples from the index point (Table 1). Since the specific activity in the shells as predicted solely from the downstream dilution was approximately the same as the observed activity, the Sr^{90} loss from the river water may be considered negligible, and it may be assumed that the living and nonliving components of the stream ecosystem are in equilibrium with both Sr^{90} and stable strontium. Apparently, Sr^{90} concentrations in the Tennessee River to a distance of 500 river miles from the release point may be predicted on the basis of dilution.

Clams, because of their life span, are useful as long-term indicators of Sr^{90}. If seasonal phenomena affect the downstream movement of Sr^{90}, this would not have been detected in the analysis reported here. Short-lived mollusks such as physid snails or sphaeriid clams may be useful as short-term indicators of Sr^{90}.

The use of specific activities to determine the behavior of mineral elements in natural waters affords an excellent opportunity to further our knowledge of the chemistry and biology of these waters. This knowledge may be used for predicting the fate of radioactive contaminants in the environment as well as for adding to our understanding of mineral nutrition required for biological productivity (*10*).

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Radiotelemetry of the Respiration of a Flying Duck

Abstract. Respirations of a flying wild mallard duck, *Anas platyrhynchos*, appear to be synchronized with wing beat in a ratio of 1 to 2. Wing beats come during exhalation and between respirations. The average number of respirations was 14 per minute for a resting duck and 96 per minute for a flying duck.

There has been considerable speculation by various workers about the synchrony or lack of it between respiration and wing beat in birds (*1*). Tomlinson and McKinnon (*2*) appear to have evidence that respiration and wing beat in the pigeon, *Columba livia*, are synchronized in 1-to-1 relationship.

While engaged in radio tracking of wild mallard ducks, *Anas platyrhynchos*, for studies of bird orientation, we accidentally discovered that the miniature radio transmitter being used was telemetering respiration. The transmitter was originally designed for tracking wild rabbits, *Sylvilagus floridanus* (*3*). Electrically, it is a one-transistor, crystal-controlled Colpitts oscillator (see circuit diagram, Fig. 1). The tank coil for the oscillator acts also as a magnetic dipole transmitting antenna. In the present study, the antenna was a loop constructed of a thin (0.008-inch thick), flexible, copper strip 0.25 inch wide and 12 inches long. A slight change in the shape of the loop causes a change in the frequency and output (microwatts) of the transmitter, which may be heard and recorded through a sensitive receiver. We used a Collins R-390A receiver, and the recorder was a Sanborn eight-channel unit.

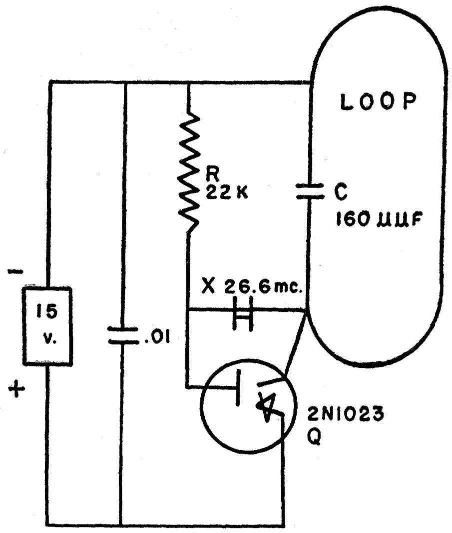

Fig. 1. Circuit diagram of the transmitter used to telemeter respiration from ducks. The values of *R* and *C* may vary considerably, both being dependent on slight differences in the transistor and the loop.

The transmitter was attached to the duck by plastic electrical tape which was wrapped once around the battery and several times around the duck's body just behind the wings. The transmitter thus rode on the center of the duck's back, while the antenna loop encircled the body immediately anterior to the legs. The total weight of the transmitter including the battery and loop antenna was 38 grams, most (25 grams) of which was battery.

Upon release, the duck (an adult male) flew north, then circled east of the tracking station to fly eventually out of tracking range to the southwest. Within 5 minutes of leaving tracking range, the duck returned on a straight

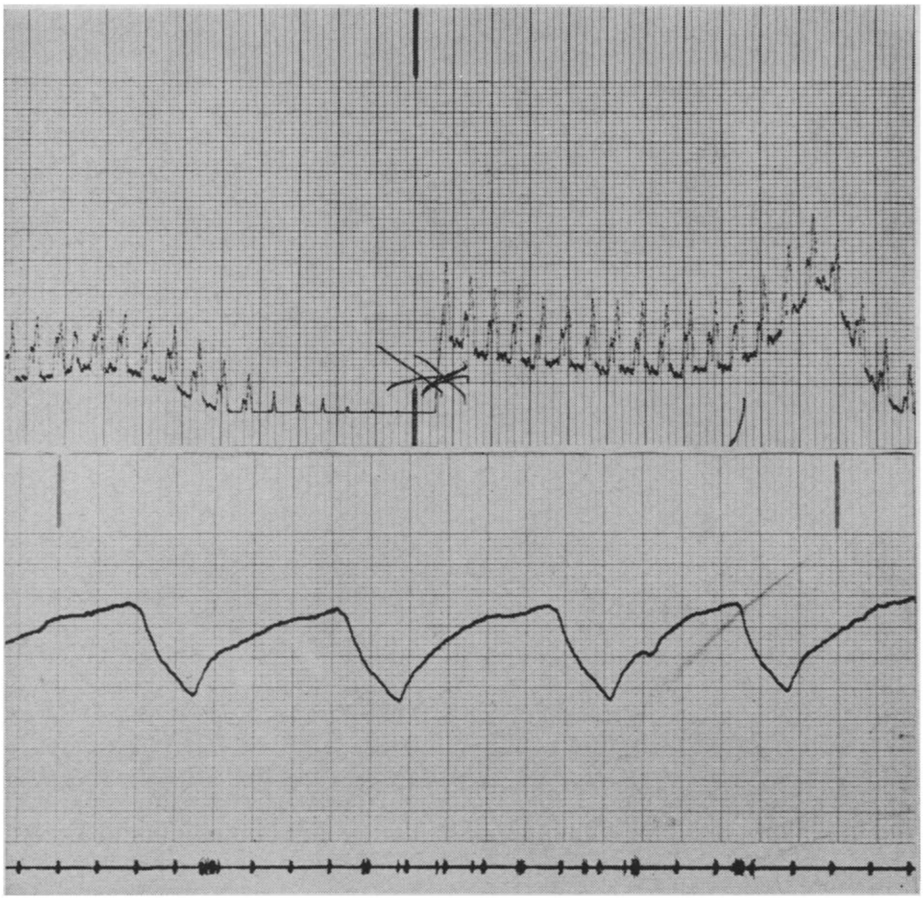

Fig. 2. Recording of frequency changes caused by respiration and wing beat of a flying duck (above) and respiration of a resting duck (below). The flat part of the upper recording was caused by passage of the duck directly over the receiving antenna, and the jump after it (marked with an *X*) was a manual adjustment of the recorder. Every five spaces represents 1 second of time.

course headed northeast. The course of the duck's flight brought it nearly directly over the tracking station at which time the flight characteristics and altitude (approximately 500 feet) were observed. The duck's speed of flight appeared to be normal (about 40 miles per hour). The respirations of the duck could be heard through the loud-speaker of the radio receiver, and at the same time, the flight of the duck was observable. There appeared to be several wing beats per respiration, but synchrony could not be accurately determined. Before the duck passed overhead the Sanborn recorder was activated, and the respirations of the duck in flight were recorded for several minutes. Later, the respirations of another mallard drake were recorded while the duck was at rest. Figure 2 is a portion of the recording of the respirations of these two ducks. The average respiration rate of the flying duck was 96 respirations per minute, while that of the resting duck was 14 respirations per minute.

After passing over the tracking station, the duck flew an irregular course for another half-hour before settling in a nearby field at nightfall. At 10 P.M. the Sanborn recorder was turned on at a slow chart speed (30 mm/min) and allowed to run until 8 the following morning. Thus the respirations of the duck were recorded through the night. A morning flight of about 1 minute's duration was recorded at 6:20 A.M., after which the duck settled in another field and presumably began feeding. Respiration rates at the slow chart speed used during the night and in the morning made accurate counts impractical, but a slight increase in respiration rate appeared to take place after the morning flight.

Close examination of the curve form of the respirations of the flying duck (Fig. 2) show a consistent interruption in the ascending portion of each curve and also a small frequency change between each respiration curve. We believe that these aberrations in the record of the respirations of the flying duck represent wing beats. Thus, it appears that respiration and wing beat are synchronized, not in a 1-to-1 ratio as in the pigeon (*2*), but with two wing beats to every respiration. This would average approximately 192 wing beats per minute. On another portion of the record of the respirations of the flying duck (Fig. 2) was a 1-second interval when the duck apparently did not breathe. During this interval, four minor but sharp and regular changes in frequency occurred. These frequency changes appear to be identical with those observed between the respirations. If it is assumed that these marks represent wing beats, the extrapolation would give a wing beat of 240 per minute. Since this 1-second interval was apparently an aberration in the regular flight pattern, to say nothing of the difficulties of extrapolating the events of 1 second to a full minute, this estimate of rate of wing beat is probably less reliable. However, it could mean that there were three wing beats per respiratory cycle, one beat of which is obscured on the graph.

The respirations of the resting duck show a quick inhalation (the downward slope of the curve) taking approximately 1.5 seconds and a gradual exhalation taking approximately 3 seconds. In contrast, the respirations of the flying duck show a quick exhalation, interrupted by a wing beat and an immediate inhalation, both taking approximately 0.4 second. The bird then apparently holds its breath for approximately 0.4 second, interrupted by a wing beat, before exhaling and inhaling again.

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