Kinematics of phalarope spinning

SIR — Phalaropes are wading birds that spin on the water, presumably to feed[1–5] because they peck while spinning. Recently, we demonstrated with high-speed photography that phalaropes do indeed feed while spinning[6]. These very small birds are the only vertebrates that spin. Larger birds probably could not spin fast enough to upwell prey. Spinning is energetically costly, about four times resting metabolism — phalaropes do not spin if adequate surface prey are available. Here we report the details of how these birds feed while spinning.

We first thought that phalaropes produce a bounded vortex with central upwelling, but Sutton[1] and others[4] report phalaropes "twirling in water many fathoms deep", far too deep for toroidal flow. Instead, red-necked phalaropes produce a subsurface meridianal flow that concentrates and upwells prey in an upward momentum jet due to differential effort by the legs (Fig. 1). Each 1-second spin requires 7–8 kicks. The lobed toes spread for thrust and fold for recovery. The outer tarsus travels through an angle of between 90° and 110°, the inner only between 35° and 50°. The bird leans in and circles with a radius of half the waterline length, the bill above the upwelled core. The bird's body circles continuously, but its head moves in discrete 45° snaps, separated by brief pauses, like a spinning ballerina. Phalaropes detect prey, thrust, seize, transport and swallow in less than half a second[6], at a rate of 180 pecks per minute[7].

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Photograph by B. Littlehales

FIG. 1 Spinning red-necked phalarope generates an upwelled plume of prey (brine shrimp) and fluorescein dye. Birds were induced to feed in a 1-m^2 aquarium by placing brine shrimp in an open petri dish on the bottom, in water shallow enough for the birds to reach the food by dipping the bill and head under water. The water level was then raised gradually until the birds spontaneously spun to feed. Flow patterns were revealed by filling the petri dish with hypersaline water mixed with fluorescein dye and prey that remained in the dish until the birds began to spin.

We simulated water circulation generated by spinning phalaropes with a motorized toy submarine attached rigidly to a surface float, with the propeller at the same depth as the feet of the bird. The 10-cm submarine generated a rotational eddy in solid-body rotation within the turning circle and an irrotational eddy outside, identical to that produced by phalaropes[8]. Upwelling began nearly instantaneously in the centre of the circle. The water surface bounded the upwelled water, which was deflected radially in a 2-cm layer. The flow was thus strongly three-dimensional, with comparable vertical and radial velocities and an upwelling depth of ten times the radius.

Phalaropes kick water away at the surface so rapidly that the water surface is depressed and deeper water flows upwards to replace it. The bird thus deflects the free surface, driving an upward momentum jet. This intense upwelling differs from classical oceanographic upwelling, wherein vertical velocity is smaller than horizontal velocity by several orders of magnitude. When phalaropes spin they swim sideways (Fig. 2), moving their centre of rotation and extracting food from new areas.

In 1.5-m-deep aquaria, particles 0.5 m under the submarine were upwelled, but in those shallower than 0.5 m a boundary layer developed on the bottom[9], with central upwelling. When spinning ceased, the bottom was cleared under the turning circle. This also occurred when phalaropes spun over a dish with dead brine shrimp immersed in brine stained with dye. A green, tornado-like tube of dye and prey rose upward from the dish (Fig. 1), rotating opposite to the rotation of the bird as it began to feed.

Spinning concentrates prey into the upwelling jet where the phalarope feeds faster than any other bird. Rapid, localized feeding is effective when food is patchy or out of reach, as with the bird's planktonic prey at sea. Spinning is effective when prey are aggregated and layered against a shallow bottom and subject to accumulation by medially directed bottom currents and when prey are layered or immobilized by cold[2]. Tinbergen noted[2] that phalaropes do not spin when it is windy. Wind-generated surface shear, Langmuir cells, and breaking waves may interfere with bird-generated upwelling jets.

a

b

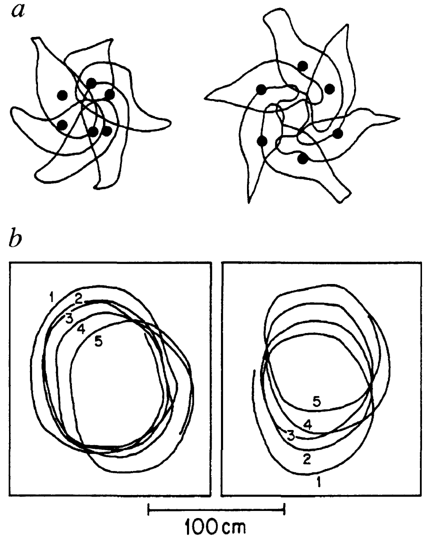

FIG. 2 Motion analysis of a spinning phalarope. Phalaropes in the aquarium were videoed from above and feeding was analysed in two dimensions using an ExpertVision motion analysis system (Motion Analysis Corp., Santa Rosa, California). *a*, Outline of a phalarope during a single spin in a digitized sequence. Filled circles, centroids of the bird's outline in each video frame. *b*, Frame-by-frame centroid tracks for two birds during five sequential spins. Each spin was slightly offset from the former so that the spinning phalarope travelled slowly over the water; spinning velocity for five sequences with three different birds averaged 0.28 m s^{-1} (s.d. = 0.03 m s^{-1}).

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