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THE BRISTLE-THIGHED CURLEW LANDFALL OF 1998: CLIMATIC FACTORS AND NOTES ON IDENTIFICATION

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The Bristle-thighed Curlew (*Numenius tahitiensis*) undertakes one of the longest known transoceanic migrations of any shorebird, commuting between its breeding range in western Alaska and its wintering grounds in the tropical Pacific. Its world population is likely less than 10,000 (Marks 1996), and its breeding population consists of approximately 3500 pairs (Gill and Redmond 1992). Prior to 1998, there were only four North American records of the Bristle-thighed Curlew south of Alaska, which is not surprising given the species' small numbers and expected migratory route.

During May 1998, however, between 13 and 17 Bristle-thighed Curlews were recorded on the Pacific coast between Point Reyes, California, and Tatoosh Island, Washington. Notably, vagrants of three other trans-Pacific migrants were also found along the same stretch of coast line that May, the Gray-tailed Tattler (*Heteroscelus brevipes*), Eurasian Whimbrel (*Numenius phaeopus variegatus* or *N. p. phaeopus*), and Bar-tailed Godwit (*Limosa lapponica*). At the same time, weather patterns over the North Pacific were strongly influenced by both the well-publicized 1997/1998 El Niño and a much less publicized but equally influential positive phase of the West Pacific Oscillation (WPO).

We hypothesize that, in general, the occurrence of a large number of long-distance transoceanic vagrants is related to extreme weather, whereas the occurrence of a single vagrant may be caused by a number of factors, including unusual weather, a defective internal compass (Berthold 1993), and ship assistance. Consequently, we examined wind and cloud patterns in the North Pacific to search for anomalies that might have contributed to the Bristle-thighed Curlew landfall. We also looked at broader climatic phenomena (El Niño and the WPO) for their part in any unusual conditions.

Evaluation of the May 1998 Bristle-thighed Curlew reports required a thorough understanding of this species' identification. Therefore, we reviewed previously published identification criteria and assessed these further by examining the specimens in the Burke Museum, University of Washington, Seattle.

METHODS

We located and assessed past records of the Bristle-thighed Curlew and other species by reviewing regional texts (see Literature Cited), reviewing *American Birds/Field Notes*, and contacting state and provincial bird records committees. Sightings from the 1998 invasion were first compiled by a review of Michael Patterson's Bristle-thighed Curlew World Wide Web page and from discussions with active birders. We assessed the reports by examining descriptions, photographs, and in one case, a wing of the bird involved. The photographs were gleaned mostly from Patterson's Web page, the descriptions were obtained from the observers, and the wing was inspected at the Burke Museum (UWBM 59322). We evaluated identification criteria for the Bristle-thighed Curlew by reviewing previously published analyses and photographs (Johnsgard 1981, Hayman et al. 1986, Paulson 1993, Rosair and Cottridge 1995, Higgins and Davies 1996), by studying specimens at the Burke Museum, and through discussion with observers familiar with this species (David James, Dennis Paulson, Peter Pyle, and Sievert Rohwer).

Kevin Aanerud and Mlodinow compared the eight full specimens and five spread wings of the Bristle-thighed Curlew with 39 full specimens and 25 spread wings of the Whimbrel, mostly *N. p. hudsonicus*, but including some *variegatus* from eastern Asia. Three of the Bristle-thigheds were in relatively fresh plumage, two from April and one from August. The remaining five whole specimens were somewhat worn adults collected in October. All Bristle-thighed wings were from fall. We measured thickness of tarsi 2 cm below the tibiotarsal joint.

Our estimates for the total number of Bristle-thighed Curlews making landfall south of Alaska were based on the number of birds seen, the amount of sandy beach habitat between Tatoosh Island and Point Reyes, and the extent to which this habitat that was surveyed. Linear miles of sandy beach habitat were estimated from geological maps for California, Oregon, and Washington. This habitat was denoted as Quaternary sand or Quaternary beach and dune sands on these maps. Estimates of the amount of this habitat searched were based on interviews with active birders. Estimates of total birds found were made on both most conservative and least conservative criteria. For the most conservative estimate, all sightings within a 12-day period and a 10-mile radius were considered to be of the same individual(s). The 12-day period was based on the stay of the birds at the south jetty of the Columbia River, the longest we know of. The least conservative estimate supposed that all nonconsecutive sightings at least 1 mile apart were of different individuals.

We arrived at the most conservative estimate of total curlews involved in the 1998 event by expanding the most conservative estimate of birds by the most conservative estimate of sandy beach habitat surveyed. Similarly, we derived the least conservative estimate by expanding the least conservative estimate of birds by the least conservative estimate of habitat. We did not extrapolate beyond the northern and southern edges of the observed area of the curlew's occurrence.

The monthly average WPO index and the Southern Oscillation index (SOI) were both made available by the National Oceanic and Atmospheric Administration (NOAA)/Climate Prediction Center in Washington, D. C. These indices are expressed by a positive or negative number that measures the strength of the WPO and El Niño/Southern Oscillation, respectively. To search for anomalous winds between 15 April and 15 May 1998, we used daily averaged data from the National Centers for Environmental Prediction/National Center for Atmospheric Research Reanalysis (Kalnay et al. 1996), which were obtained from the NOAA Climate Diagnostics Center in Boulder, Colorado.

We calculated model trajectories to estimate the path taken by the migrating Bristle-thighed Curlews, using the winds at the 600-mb pressure level. This level, which approximately corresponds to an altitude of 4 km above sea level, is selected because that is the typical elevation for shorebirds migrating over water (Richardson 1976, Williams et al. 1977, Elkins 1988, Kerlinger and Moore 1989, Berthold 1996). We calculated the trajectories for six consecutive days beginning 26 April 1998. The initial location of the curlews is specified as the southernmost end of the 20 m/s northerly wind contour (the dashed contours in Figure 2) in the north-central North Pacific. We then assumed that the curlews flew parallel to the local wind vector, i.e., drifted downwind, at an air speed of 25 m/s (similar general conclusions are obtained with other realistic air speeds). Mathematically, this can be written as

$$\mathbf{V} = \mathbf{V}_w + a\mathbf{r},$$

where the vector $\mathbf{V}$ is the bird's ground speed, $\mathbf{V}_w$ is the observed wind vector, a = 25 m/s (the bird's air speed, Marks and Redmond 1994a), and $\mathbf{r}$ is a unit vector parallel to $\mathbf{V}_w$. The equations for the longitudinal and latitudinal displacement of a bird undergoing downwind drift are

$$dx = U(t)dt; \; dy = V(t)dt,$$

where dx is the eastward displacement and dy is the northward displacement of a bird moving with an eastward ground speed at time t of $U(t)$ and a northward ground speed at time t of $V(t)$ over a time interval dt. The appropriate spherical representations are used for dx and dy (see Holton 1992), and the time step dt is specified as one hour. With this approach, the temporal changes to the observed wind pattern throughout downwind drift are taken into account. Also, temporal and spatial mathematical linear interpolation is performed as the observed wind vectors are obtained from NOAA Climate Diagnostics Center as daily averages on a 2.5° latitude/longitude grid.

RESULTS AND DISCUSSION

Status and Distribution

Bristle-thighed Curlews are known to breed only in Alaska, where they have been found in the Nulato Hills (the low mountainous region just north and east of the lower Yukon River) and across the northern half of the

Seward Peninsula (Handel and Dau 1988, Kessel 1989). They typically arrive at their breeding grounds in mid-May but have been found there as early as 5 May (Kessel 1989); a record from Attu Island on 2 June 1993 (AB 47:444) was likely of a late northbound migrant. After nesting, much of the population stages in Alaska's Yukon–Kuskokwim delta before migrating south, with smaller numbers staging along the Seward Peninsula coast (Handel and Dau 1988, Kessel 1989). The first southbound adults appear at these staging areas as early as late June. A larger influx of adults occurs in late July, followed by adults with juveniles in early August (Handel and Dau 1988). By mid-to-late August most adults and juveniles are gone. The latest date from Alaska is 18 October 1994 on St. Lawrence Island (FN 49:85). In both the upland breeding areas and the coastal staging areas, dwarf shrub habitat is preferred (Kessel 1989).

Little is known of Bristle-thighed Curlews during migration. The first possible stop for southbound birds is the northwestern Hawaiian Islands, some 4000 km away. These islands serve as the wintering ground for 700 to 800 individuals, but few if any passage migrants stop there during either fall or spring (Marks and Redmond 1994a,b). Consequently, those curlews wintering farther south in the Pacific likely travel at least 6000 km without resting during both fall and spring migration. Bristle-thighed Curlews have been known to migrate in the company of Pacific Golden-Plovers (*Pluvialis fulva*) (Marks and Redmond 1994a) but rarely associate with Whimbrels, even at mutual staging sites in Alaska (Handel and Dau 1988).

The Bristle-thighed Curlew winters commonly in the northwestern Hawaiian Islands, eastern Micronesia, and eastern Polynesia. It is less common in central Polynesia and Fiji and rare in the main Hawaiian Islands and western Micronesia (Pratt et al. 1987, Marks and Redmond 1994b). The bulk of the winter range is, therefore, between 135° W and 175° E. There are four records from farther south or east in the Pacific: two from the Kermadec Islands during September 1972 (Veitch 1974), one from Norfolk Island during January 1968 (Turbott 1990), and one from Easter Island (Vilina et al. 1992).

Bristle-thighed Curlews can be found year round on their wintering grounds but are most numerous between September and April (Gill and Redmond 1992). Birds remaining through the austral winter are largely immatures, which do not migrate back north until they are approximately 34 months old (Marks 1993, Marks and Redmond 1996). The favored winter habitats include open dry grasslands, saltpans, edges of tidal channels, and sandy beaches (Pratt et al. 1987, Gill and Redmond 1992), but some birds also venture into brushland and open woodlands (P. Pyle pers. comm.).

On the northwestern Hawaiian Islands, returning adults arrive from mid-July to late August, juveniles mostly between mid-August and early September (Marks and Redmond 1994a), though some appear as late as early October (P. Pyle pers. comm.). Spring departures occur almost entirely during very late April and early May (Marks and Redmond 1994a, P. Pyle pers. comm.). Bristle-thighed Curlews wintering in Hawaii mostly inhabit open dry grasslands but congregate on sandy beaches, mudflats, airplane runways, and similar areas just after fall migration and just prior to spring migration (J. Marks, P. Pyle pers. comm.).

On the main Hawaiian Islands, Bristle-thighed Curlews are quite scarce. Historically, only one or two birds were seen, usually between late August and early October, and usually near Kahuku, Oahu (R. Pyle pers. comm.). Starting about 1990, individuals began wintering, and the numbers during fall increased. During the winter of 1997–98, there were at least 13 birds at Kahuku, and, for the first time, a few may be summering (R. Pyle pers. comm.).

Records Prior to 1998

Prior to 1998, there were only four accepted records of the Bristle-thighed Curlew from North America outside of Alaska. The first of these is of a bird collected at Grant Bay at the northwestern end of Vancouver Island, British Columbia, on 31 May 1969 (Richardson 1970). The second is of two photographed at Bandon, Oregon, on 16 September 1981 (Gilligan et al. 1994). The third is of one seen at Leadbetter Point, Washington, on 1 May 1982 (Widrig 1983), and the fourth was recorded at Blackie Spit along Boundary Bay, British Columbia, 13–14 May 1983 (Campbell et al. 1990).

Several birds reported and published as Bristle-thighed Curlews were later rejected by local authorities. One photographed at Cox Bay, near Tofino, along the western shore of Vancouver Island on 1 September 1982 was initially identified as a Bristle-thighed (AB 37:904), but later evaluation of the photograph suggests that it may well have been a Whimbrel (Campbell et al. 1990, D. Paulson, pers. comm.). A report from Victoria, British Columbia, on 11 September 1986 is considered hypothetical (K. Taylor pers. comm.). Widrig (1983) referred to two Bristle-thighed Curlews seen flying past Leadbetter Point on 18 May 1980—two years prior to his sighting. Unfortunately, the description of these birds, seen only in flight, is very brief, and the report must be left as hypothetical.

Notably, records of vagrants in Asia are also quite unusual and are apparently limited to Japan. Brazil (1991) listed 13 Japanese records, few with actual dates. Multiple records have come from May and September, with single records from March and July.

Records from 1998

The 1998 Bristle-thighed Curlew invasion started quietly on 6 May when David Lauten and Kathy Castelein tentatively announced a Bristle-thighed Curlew at Floras Lake, Curry County, Oregon. Regional birders' interest grew dramatically when two more were seen on 8 May flying past Ocean Shores, Grays Harbor, Washington (R. Sundstrom, H. Opperman pers. comm.). The ensuing three weeks led to 13 more reports that could have involved as many as 22 additional birds, giving a total of 15 reports consisting of up to 25 individuals (Appendix 1). Of these 15 reports, we found three (involving a total of eight birds) to be lacking details sufficient to be included in our analysis.

On the basis of the most and least conservative criteria under Methods, between 13 and 17 Bristle-thighed Curlews were seen, all between 6 and 25 May (*contra* Patterson 1998). Initial detection ranged from 6 May to 19 May, with a median of 13 May. All but two records came from sandy beaches, the birds at Tatoosh Island and Battery Point occurring on marine terraces (Tertiary conglomerate). The discrepancy between the upper and lower estimates comes mostly from Ocean Shores/Westport, Grays Harbor County, Washington. At this location, one or two Bristle-thighed Curlews were reported only intermittently between 8 and 25 May, despite nearly continuous coverage, implying that several individuals or pairs may have passed through. The actual number of birds seen at Westport/Ocean Shores is somewhere between two and six, probably closer to six.

Between 40 and 65 miles of the 309 miles of beaches between Point Reyes and Tatoosh Island was surveyed by birders. Extrapolation by the most and least conservative methods leads to an estimate of 60 to 150 Bristle-thighed Curlews making landfall on the Pacific Coast of the contiguous United States. If the breeding population is roughly 3500 pairs (Gill and Redmond 1992), the 1998 invasion involved between 0.9 and 2.1% of breeding Bristle-thighed Curlews. If additional birds were lost at sea, an even greater proportion of the population was affected.

Parallel Vagrants

The Bristle-thighed Curlew is not the only shorebird that breeds in Beringia, winters on tropical Pacific islands, and is a vagrant along the coast of North America south of Alaska. Other such taxa are the Gray-tailed Tattler, Asiatic Whimbrel (*N. p. variegatus*), Bar-tailed Godwit, Red-necked Stint (*Calidris ruficollis*), and Sharp-tailed Sandpiper (*Calidris acuminata*). Of these, the Gray-tailed Tattler, Asiatic Whimbrel, and Bar-tailed Godwit were reported south of Alaska during May 1998 (Appendix 2)—the first time three of these species were reported during the same spring, an unprecedented event that seems likely related to the same weather factors that misplaced the Bristle-thighed Curlews. Surprisingly, Pacific Golden-Plovers did not occur in unusual numbers during the spring of 1998 (*contra* Patterson 1998), despite having a migratory route similar to that of the Bristle-thighed Curlew.

The Role of Weather

Given that Bristle-thighed Curlews migrate long distances over the open ocean and infrequently stray off course, one might presume that they have extraordinary navigational skills and are able to cope well with adverse weather. Williams and Williams (1990), however, suggested that transoceanic migrants do not have exceptional navigational skills. Current theory presents a picture of overwater migration of three stages: (1) when departing the tropics in spring, birds tend not to depart into strong headwinds—a trait of the Bristle-thighed Curlew (Marks and Redmond 1994a); (2) there is little or no compensation for lateral wind drift during overwater migration, with birds appearing to maintain a constant compass heading (Richardson 1976, 1991, Alerstam 1981, Williams and Williams 1988, Berthold 1996); (3) as birds approach their destination, they use additional navigational skills, such as compensating for wind drift and using landmarks (e.g., Williams et al. 1986).

There are three main causes of weather-related vagrancy among birds: strong head winds, strong lateral winds, and deep and horizontally extensive cloud cover. Unusually strong head winds rapidly deplete the fat reserves of migrant birds, particularly dangerous to those flying over the ocean. Excessive lateral winds can cause overwater migrants to drift far off course, while deep clouds lead to a reduction in visibility that can lead to disorientation (Lack and Eastwood 1962, Able 1982a, Elkins 1988, Richardson 1990, Berthold 1993, Moss 1995). Both headwinds and heavy cloud cover can sometimes result in downwind orientation (Williamson 1959, Able 1982a,b, Able et al. 1982, Elkins 1988, Moss 1995), as this strategy increases the likelihood of reaching land.

El Niño and the West Pacific Oscillation

The occurrence of the Bristle-thighed Curlews coincided with both a large El Niño and a large positive phase of the WPO. The well-known El Niño phenomenon is characterized by anomalously warm surface water in the eastern equatorial Pacific Ocean and is accompanied by a strengthening of the westerly winds in the eastern subtropical Pacific. This change in the wind pattern can be seen by comparing the average 300-mb wind vectors off the west coast of Mexico from 15 April to 15 May 1998 (Figure 1a) to the 10-year average wind vectors for the same period (Figure 1b). (The 300-mb pressure level is about 8.5 km above sea level, well above the elevation of migrating shorebirds, as discussed earlier. However, we examine the 300-mb winds because midlatitude storm systems are to a large degree steered by the winds at this level.) The WPO, identified through the application of a rotated principal-component analysis (Barnston and Livezey 1987), involves changes to the wind pattern in the northwestern and north-central North Pacific. In the north-central North Pacific, where Bristle-thighed Curlew migration normally takes place, the positive phase of the WPO is characterized by a strengthening of the northerly component of the winds (compare Figures 1a and 1b).

The extraordinary circumstances of the spring of 1998 are determined by comparing the SOI and WPO indices with those of previous years. The SOI has been measured as far back as 1882, the WPO index to 1950. The SOI for April 1998 is tied with that for 1987 for the second most negative value since 1882 (a large negative SOI value denotes El Niño). The WPO index for the spring of 1998 had the second largest positive value during the past half century.

Wind Patterns

As noted above, shorebirds in general migrate over water at about the 600-mb level. Therefore, we searched dates between 15 April and 15 May 1998 for strong *anomalous northerly* or strong *anomalous westerly* winds (speeds at least two standard deviations greater than average) at 600 mb in the tropical and midlatitude North Pacific west of 140°W. Analyses at other pressure levels, from sea level to 250 mb, yielded essentially the same results as those at 600 mb. We confined the search to this region because it encompasses the Bristle-thighed Curlew's normal migratory route. For this analysis, we define the anomalous wind vectors as the difference between the observed vector wind field on a given day and the average vector wind field on the same calendar day, averaged from 1988 to 1998. We emphasize exceptional winds because curlews have presumably evolved to compensate for normal winds.

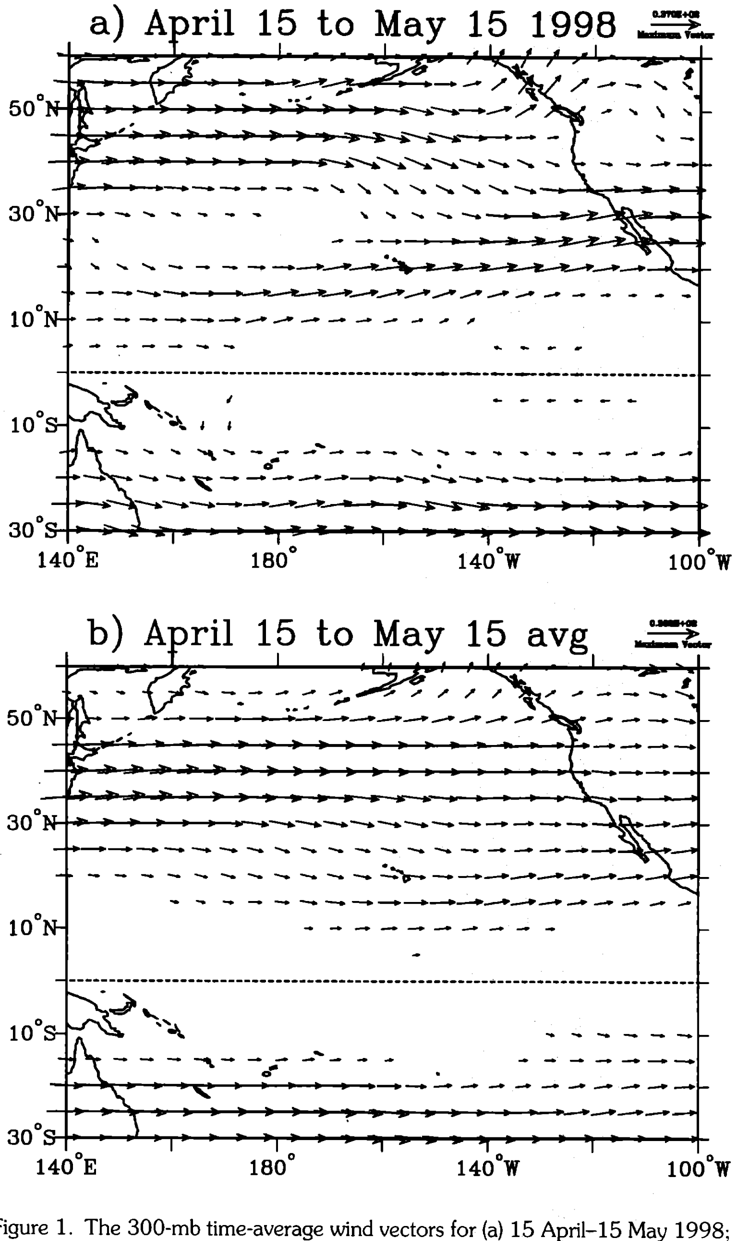


Figure 1. The 300-mb time-average wind vectors for (a) 15 April–15 May 1998; (b) 15 April–15 May 1988–1998. The maximum vector length, in units of m/s, is indicated at the top right corner of each frame.

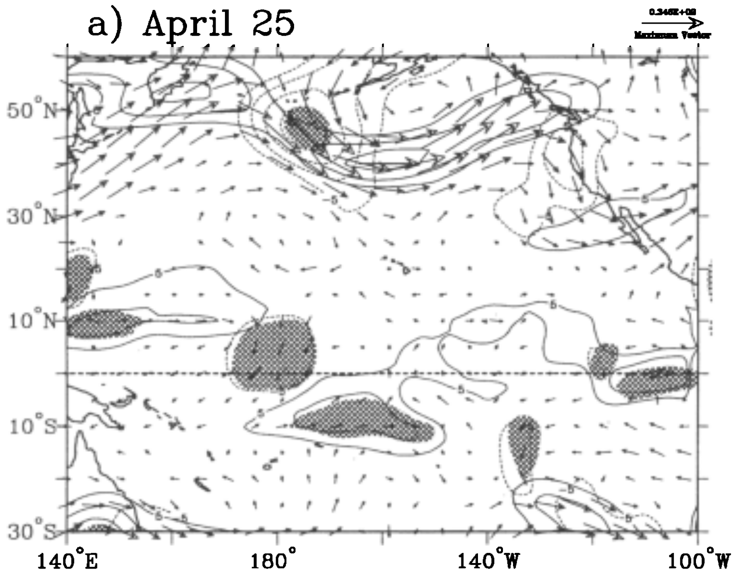
We found anomalies of greater than two standard deviations only between 26 April and 2 May 1998. We illustrate the daily averaged winds on alternate days beginning on 25 April 1998 in Figure 2, which shows two regions of large anomalies, one between 30° and 50° N, the other between 5° and 15° S, both in the central Pacific. The former region involved both anomalous northerly and westerly winds, the latter just anomalous westerly winds.

At 40°N, 160° W on 25 April 1998, there was a weak trough (note that the winds rotate counter clockwise in a trough) that rapidly deepened (extending far to the south) over the following four days. This trough deepening, which is very unusual, is consistent with the influence of the positive phase of the WPO, with its anomalous northerly winds between 25° and 50° N and between 170° and 130° W (compare Figures 1a and 1b). Such anomalous winds correspond to an enhancement of the so-called stretching deformation field (Dutton 1995), which results in troughs being "stretched" southward and leading to substantial trough deepening (Lee 1995, Whitaker and Dole 1995; Figure 2). Coinciding with this trough deepening is a strengthening of northerly winds, reinforced by the positive phase of the WPO. Further amplification of this trough was likely due to a weak cyclone (denoted by an X in Fig. 2) at the ocean surface on 27 April 1998. The location of this cyclone, east of the 600-mb trough, was appropriate for a mutual interaction with the trough, resulting in a rapidly amplifying storm and stronger winds at all levels via baroclinic growth (Hoskins et al. 1985, Holton 1992). In the other region of interest, the tropical Southern Hemisphere, analyses at various pressure levels (not shown) revealed an extension of anomalous westerlies down to sea level but a decline in the amplitude of the anomalies at higher levels. Such characteristics are consistent with westerly wind bursts (e.g., Kiladis et al. 1994).

If the northerly headwinds were sufficiently strong, they could have depleted a curlew's energy reserves before it reached Alaska. Furthermore, these headwinds covered a longitudinal range broad enough that they could have affected birds heading north from anywhere in the species' winter range. For westerly winds, anomalous, not total, winds are relevant, because Bristle-thighed Curlews have presumably evolved to compensate for lateral drift by the average wind. The solid contours in the central Pacific in Figure 2 indicate that the anomalous westerly winds in both hemispheres could have also caused lateral wind drift, particularly for birds wintering in eastern Polynesia.

We first considered the influences of the anomalous westerly winds in the Southern Hemisphere, whose maximum speed was approximately 15 m/s (Figure 2c). If migrating curlews in this region are flying due north at an air speed of 25 m/s and encounter anomalous crosswinds of 10 m/s over 10 degrees latitude, they will drift eastward by a distance of approximately 4 degrees longitude. Clearly, this amount of eastward drift could not, by itself, account for the Bristle-thighed Curlew landfall. However, it may have contributed to the landfall indirectly if this drift was sufficient to lead the birds into the strong headwinds in the North Pacific.

The anomalous westerlies in the Northern Hemisphere, just to the south of the surface cyclone, were stronger than those in the Southern Hemi-



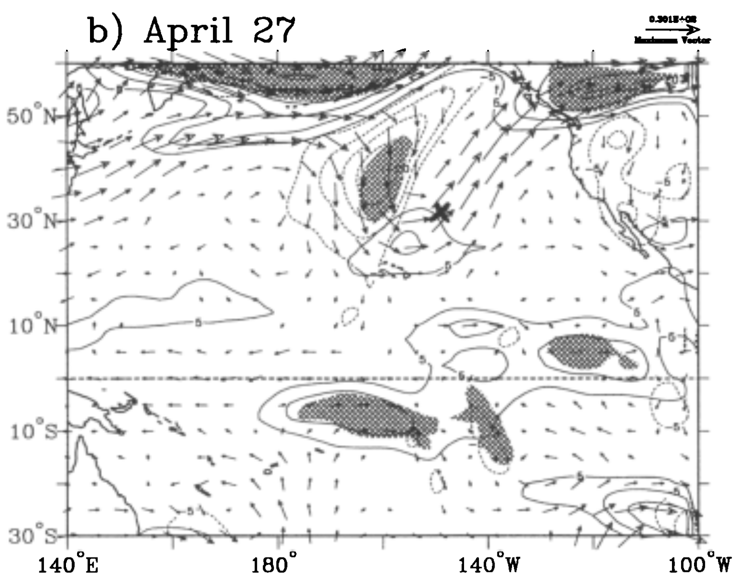
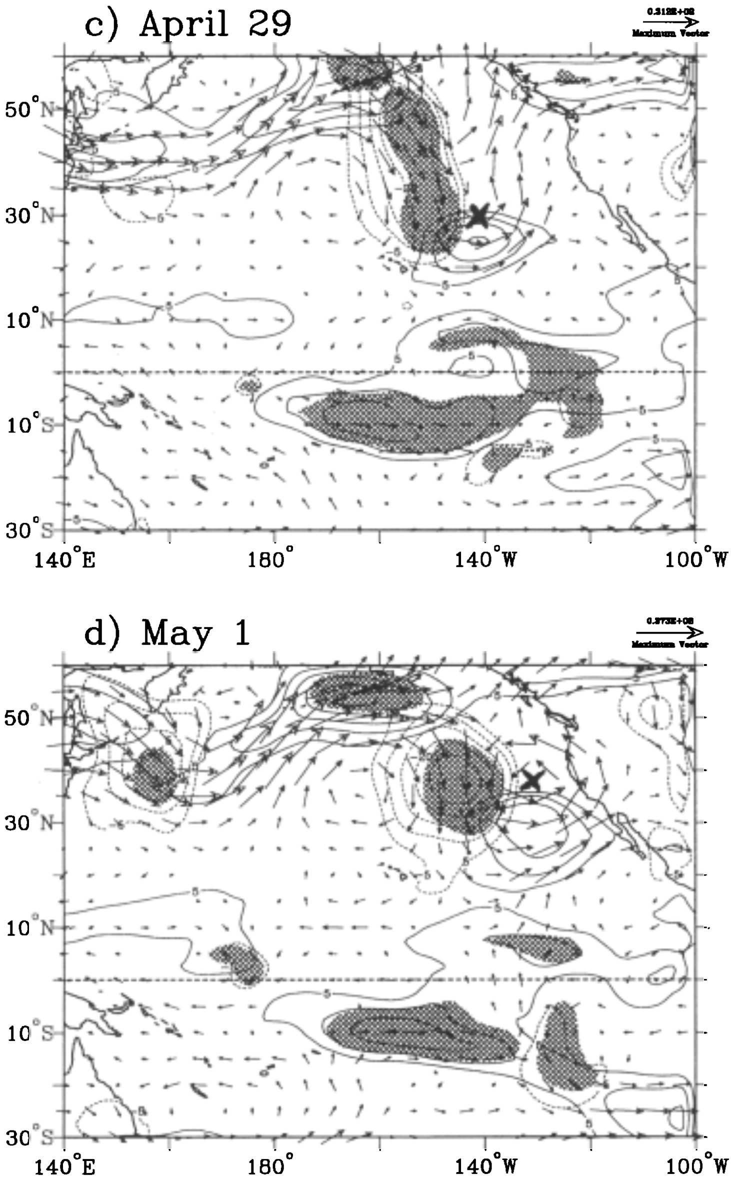


Figure 2. Total 600-mb wind vectors for (a) 25 April 1998, (b) 27 April 1998, (c) 29 April 1998, (d) 1 May 1998. Solid contours, anomalous westerly winds; dashed contours, anomalous northerly winds. The contour interval is 5 m/s. Shading indicates those regions where the anomaly exceeds two standard deviations, and the "X" denotes the location of the surface low. The maximum vector length, in units of m/s, is indicated at the top right corner of each frame.


c) April 29
50°N
30°N
10°N
10°S
30°S
140°E
180°
140°W
100°W
d) May 1
50°N
30°N
10°N
10°S
30°S
140°E
180°
140°W
100°W

sphere. If we assume an average anomalous crosswind of 15 m/s over 10 degrees latitude, the eastward drift would be 6 degrees longitude, again, insufficient to account for the 1998 landfall.

On the other hand, an examination of the northerly winds in the North Pacific quickly reveals that they were sufficiently strong to be a major impediment to any northbound Bristle-thighed Curlew. The maximum northerly wind speed in this region was in excess of 25 m/s, about the airspeed of a migrating curlew. Thus, birds flying into this wind would have made little headway and might have even been pushed backward. Since these strong headwinds spanned as much as 20 degrees of latitude, the birds likely depleted their fat reserves for little gain. To try to avoid these adverse headwinds, the migrating curlews could have dropped to a lower altitude, a response known in other species (see references in Richardson 1990). In this case, however, such an adjustment would have been of limited benefit. For example, at 850 mb (approximately 1.5 km above sea level), the strongest headwinds (not shown) were still in excess of 20 m/s, and at the surface, the maximum headwinds (not shown) varied between 10 and 15 m/s. Furthermore, a reduction in flight elevation to well below 850 mb would have been an unattractive alternative, obliging the birds to fly through a fairly extensive cloud cover (see below), which can seriously impair a bird's ability to orient correctly (Richardson 1990). Therefore, the Bristle-thighed Curlews could not have avoided the widespread anomalous northerlies in the North Pacific, and it is these winds more than the anomalous lateral winds that likely accounted for the curlew landfall.

Role of Clouds

As discussed earlier, extensive cloud cover can seriously disorient migrating birds. During the last few days of April 1998, there was fairly extensive cloud cover over much of the North Pacific. All of the cloud tops, however, were at a low elevation, except for high clouds several hundred kilometers from the storm center northeast of Hawaii (for example, see the infrared satellite image from National Climatic Data Center for 29 April at the World Wide Web site http://www.ncdc.noaa.gov/pub/data/goesbrowse/1998/g9ir29APR199800.jpg). Thus, except for any birds that might be inside the storm, curlews migrating at their usual altitude should have been well above the clouds, so cloud cover was unlikely to have played a significant role in the 1998 landfall.

Model Trajectory Calculations

As stated earlier, there is some evidence that migratory birds orient downwind when encountering strong headwinds. Indeed, when a bird is faced with headwinds sufficient to match its airspeed, flying downwind may be its only survival strategy. Therefore, we addressed the question of whether downwind drift could have brought the migrating Bristle-thighed Curlews to the west coast of the contiguous United States by means of a series of model trajectory calculations.

We calculated model trajectories for the 600-mb pressure level, one for each of the seven consecutive days beginning on 26 April 1998. Those for the first four days are shown in Figure 3. The trajectories for 30 April to 2

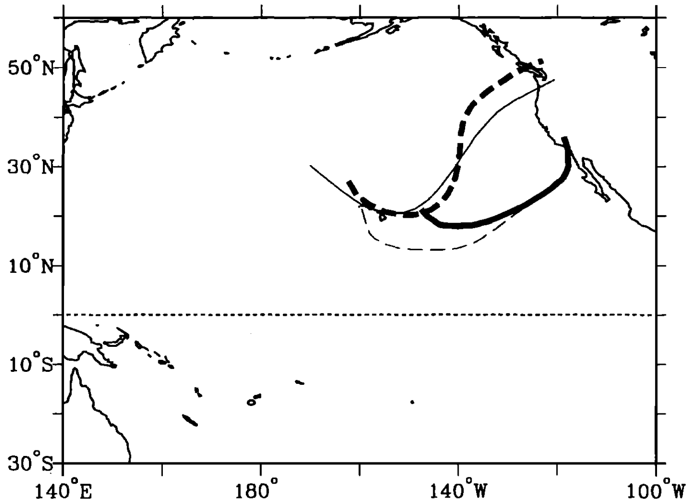


Figure 3. Model trajectories calculated for Bristle-thighed Curlews reorienting downwind in the face of insuperable headwinds. The thin solid curve corresponds to downwind drift beginning on 26 April 1998, the thick dashed curve to that beginning on 27 April 1998, the thin dashed to that beginning on 28 April 1998, and the thick solid curve to that beginning on 29 April 1998. The trajectory terminates when the theoretical bird reaches the North American west coast.

May 1998 are not shown because they predict that the curlews would have arrived in Baja California, inconsistent with actual observation. The trajectories' starting point is the western endpoint on the curves in Figure 3 and corresponds to the southernmost end of the 20 m/s northerly wind contour. These points, which correspond to the position of strongest headwinds at that latitude, represent possible locations where the curlews switched to flying downwind. The trajectories imply the birds reached the west coast between southern California and southern British Columbia, a pattern rather close to that observed. The models suggest that birds beginning downwind drift on 26 and 27 April 1998 flew to the Pacific Northwest, those starting downwind drift on 28 and 29 April 1998 to California. This southward shift in the arrival location for the latter two dates is explained by Figure 2, which shows that as the trough moved eastward, curlews undergoing downwind drift were increasingly under the influence of westerly rather that southerly winds. According to these calculations, the amount of time a bird took to reach land was 40, 36, 38, and 26 hours for the initial dates of 26, 27, 28, and 29 April 1998, respectively. During a typical year, curlews take between 25 and 37 hours to reach the Alaska coast from the starting point of the model trajectories. These results suggest that reaching the west coast of the U.S. was well within the curlews' capabilities.

According to our model, the curlews actually touched ground between 28 April and 1 May. The discrepancy between this prediction and field observations may be due to the species' rarity and the similarity to the Whimbrel.

Indeed, David Lauten (pers. comm.) almost wrote the first bird off as an odd Whimbrel. Furthermore, during the aftermath of the landfall several birders in central and northern California reported early May Bristle-thighed Curlews identified in retrospect, initially passed off as unusual Whimbrels (M. Rogers pers. comm.). Many of the birds were found in part because observers were actually looking for them and may not have been encountered or identified otherwise. Thus the lag between arrival and identification seems somewhat reasonable.

We also used the model trajectory to evaluate the contribution of El Niño to the downwind drift to the contiguous U.S. For this calculation, we used the observed wind pattern at 300 mb rather than that at 600 mb. This is because it is at the 300-mb level that El Niño has a strong influence; at 600 mb the effect of El Niño is substantially smaller (Pan and Oort 1983, Wang 1992). Thus if El Niño affected the migrating curlews, the birds would have had to move upward to a much higher elevation, an unlikely scenario. The results of this calculation, using the same four initial dates and locations as in Figure 3, bring the birds to the west coast of central and southern Mexico, far to the south of any observed curlews. Consequently, if strong headwinds followed by downwind drift accounted for the Bristle-thighed Curlew landfall, El Niño did not play a role.

Identification

The Bristle-thighed Curlew most closely resembles the Whimbrel, particularly the North American race *N. p. hudsonicus*. Characteristics considered useful have included bill shape and color, underpart color, chest markings, flank barring, undertail-covert barring, bristled thighs, upperpart coloration, rump pattern and color, tail pattern and color, under-primary pattern, underwing-covert color, leg shape, and call. We found some previously proposed distinctions to be lacking, while others were useful. In addition, apparently consistent differences in upper-primary pattern, underwing primary covert pattern, leg thickness, and behavior were uncovered by observers of the 1998 invasion or during our review of photographs and specimens. Of previously published discussions, we found Paulson (1993) to be the most accurate and informative, though the drawings in Hayman et al. (1986) and the photos in Rosair and Cottridge (1995) and Patterson (1998) are very useful.

Bill Color. When compared with the Whimbrel, the Bristle-thighed Curlew typically has more extensive pink-flesh color in the base of the bill, but there is much overlap in this mark, and its usefulness in the field is likely marginal (Paulson 1993). Also, the bill color of the Bristle-thighed Curlew varies with age, sex, and season. Females, winter adults, and immatures tend to have more extensively pale bills (J. Marks pers. comm.). On Laysan Island, during the spring of 1991, 70% of adult Bristle-thighed Curlews had attained completely black bills before migrating north, whereas less than 4% of subadults had done so (Marks 1995). Many of the spring 1998 vagrants had black or nearly black bills, but some had extensive pink.

Bill Shape. Differences in bill length, thickness, and curvature have been proposed, with the Bristle-thighed Curlew having the longer, thicker, and more decurved bill. These do not seem to hold up to the scrutiny of actual measurement (Johnsgard 1981, Hayman et al. 1986, Higgins and Davies 1996, A. Jaramillo in litt.) and review of photographs.

Underpart Coloration. The Bristle-thighed Curlew is often reported to have more richly colored underparts than the Whimbrel. However, both *hudsonicus* and the Bristle-thighed Curlew can be rather orange-buff underneath (*variegatus* lacks these warm tones). While the brightest Bristle-thigheds are more colorful than the brightest adult or juvenile *hudsonicus*, some overlap does exist between juvenile *hudsonicus* and the adult Bristle-thighed, especially those in worn plumage. Some Bristle-thigheds are more brightly colored on the flanks and undertail coverts than on the central belly (see photos in Patterson 1998), whereas *hudsonicus* does not show contrastingly brighter flanks or undertail coverts.

Underpart Markings. The presence or absence of flank barring can be a helpful adjunct in Bristle-thighed Curlew identification. Bristle-thighed Curlews typically have unbarred flanks or have the barring limited to the far anterior flanks, though one specimen shows barring well into the rear flanks, as does a photo in Gill et al. (1988). In contrast, all Whimbrels have barring well onto their rear flanks and, in some, all the way to the undertail coverts. Thus, a bird with unbarred flanks is very likely a Bristle-thighed Curlew with one caveat: both species sometimes droop their wings, hiding any flank barring.

The presence of markings on the undertail coverts is said to be diagnostic for the Whimbrel, the lack of them diagnostic for the Bristle-thighed Curlew (Paulson 1993). Some Whimbrel specimens, however, have very few markings here and in the field could easily appear unmarked even under excellent conditions. None of the Bristle-thighed Curlew specimens had any undertail covert bars, streaks, or spots. Thus, in the field, plain undertail coverts are not diagnostic for the Bristle-thighed, but marked undertail coverts eliminate it.

The breast streaking on the Bristle-thighed often appears like that of a Pectoral Sandpiper (*Calidris melanotos*), with fine vertical streaks cut off sharply at the lower breast edge. Whimbrels usually do not look this way because of cross-barring on the lower breast feathers (in many but not all birds) and their barred flanks. Bristle-thigheds lack the chest cross-bars and often lack the flank barring. The Pectoral-like appearance is only mildly suggestive of the Bristle-thighed Curlew, but cross-bars on the chest streaking are likely diagnostic for the Whimbrel.

Bristled Thighs. The thigh bristles have often been regarded as nearly undetectable in the field, yet in spring 1998 many observers found them to be readily visible. Jeff Marks (pers. comm.) finds that they are often visible at 75 meters, if one is using a good scope under good lighting conditions. Also, the thighs of Bristle-thighed Curlews often look shaggy, an aspect lacking in the Whimbrel.

Back, Scapular, and Wing Covert Markings. In Bristle-thighed Curlews, the back feathers, scapulars, and wing coverts are roughly half dark brown and half orange-buff (excepting adults in worn plumage during the fall). In adult Whimbrels, these feathers are mostly dark brown, with only 10 to 25% of the surface area consisting of pale grayish-brown (not orange-buff) feather edging and spotting.

Juvenile Whimbrels, however, are much more brightly patterned, with at least one specimen in the Burke Museum approaching a fresh-plumaged Bristle-thighed Curlew in the size and color of its markings. Also, the October Bristle-thighed Curlew specimens in the Burke Museum are far duller than the spring birds, and the upperpart markings on these individuals are well within the range found on juvenile Whimbrels. Thus, while the back/scapular/wing-covert pattern is very useful in spring, it is of much less value for juveniles.

Rump and Uppertail Coverts. The pattern and color of the rump and uppertail coverts are two of the most reliable marks for the Bristle-thighed Curlew. In the Bristle-thighed, the rump and uppertail coverts are typically orange-buff (varying from rusty to pale buff), often with a few long fine streaks, whereas in *hudsonicus* they are brown with heavy brown markings. This gives the appearance of a plain, brightly colored rump patch, while in *hudsonicus* the rump is concolorous with the back. The Asian *variegatus* has a paler and whiter rump and uppertail coverts than *hudsonicus* with fewer markings but is still more heavily marked than a Bristle-thighed Curlew. We did find one Bristle-thighed Curlew specimen with a fairly heavily marked rump, the relatively unmarked region limited to the uppertail coverts only.

Tail Pattern and Color. Tail pattern and color are also among the most reliable characters for separation of the Whimbrel and Bristle-thighed Curlew. In the Bristle-thighed, the tail is brightly colored (like the rump) with dark brown bars, whereas in *hudsonicus* the tail is medium brown with dark brown bars. Consequently, the contrast between the pale and dark bars is much greater in the Bristle-thighed.

The Whimbrel has seven to nine dark bars about 6 mm apart, the Bristle-thighed only six to seven dark bars about 7 mm apart. *Variegatus* shows the same number of dark bars as *hudsonicus*, but its pale bars are paler than those of *hudsonicus*, thus showing more contrast. These pale bars, however, are whitish, with no warm buff hues as in the Bristle-thighed.

Primary Pattern. Paulson (1993) stated that in the Whimbrel the undersurfaces of the inner web of the outer four primaries (p7–p10) show distinct, large, pale notches, whereas in the Bristle-thighed Curlew there is only diffuse mottling. This mark mostly held up to specimen examination. Unfortunately, 3 of 64 Whimbrels in the Burke Museum collection showed the mottled pattern of a Bristle-thighed, and one of the thirteen Bristle-thigheds had a Whimbrel-like pattern.

A more useful mark may be found in the upper primary pattern. In the Bristle-thighed, the uppersurface of the inner five primaries (p1–p5) shows a bold whitish rear border that cuts across the feather tip to form a prominent triangle of whitish. In the Whimbrel, the rear border is lacking on some birds and narrow on others, often extending only from p1 to p3. No Whimbrel specimens showed the white terminal triangles.

For field observers, these two marks will rarely prove useful, though in some photos and specimens they could be valuable.

Underwing Coverts. A difference in underwing covert coloration has been previously suggested (Johnsgard 1981, Hayman et al 1986, Rosair and Cottridge 1995), with the Bristle-thighed described as more brightly colored. We found no difference between the Bristle-thighed Curlew and *hudsonicus*, in agreement with Paulson (1993). *Variegatus* has quite different grayish underwing coverts.

On the other hand, the pattern of markings on the underwing coverts does appear to differentiate the Bristle-thighed Curlew from the Whimbrel. Sievert Rohwer noted that in all wing preparations in the Burke Museum, the underwing's greater primary coverts are barred heavily in the Whimbrel but are spotted or notched in the Bristle-thighed Curlew. The greater secondary coverts are heavily barred in both species, but Whimbrels have more bars.

Leg Shape. Many observers of the vagrants commented that the Bristle-thighed appeared to have shorter thicker legs and longer thicker toes. In many photos, Bristle-thigheds appear distinctly thicker legged, and at the Burke Museum Bristle-thighed Curlew tarsi averaged 6.9 mm in diameter, those of the Whimbrel 6.0 mm (these measurements may be affected somewhat by shrinkage). There was, however, a small amount of overlap. Leg length, however, is not significantly different (K. Garrett in litt, Higgins and Davies 1996). The shorter-legged appearance of the Bristle-thighed Curlew may be due to the increased thickness of the tarsi or to the tibia being obscured by shaggy thigh feathers.

Toe thickness and length are less well known. Specimens of the Bristle-thighed Curlews do appear to have thicker toes, owing mostly to more pronounced fleshy extensions at the sides of toes.

Call. The calls of the Whimbrel and Bristle-thighed Curlew are remarkably different. Whimbrels utter a series of sharp whistles, typically five to seven. Bristle-thighed Curlews usually give a two- or three-noted whistle variously described as "too-ee, tee-oo-whit, and wheet-o-weet" by Paulson (1993), "chiu-eet" by Marks and Redmond (1994a), and "chi-u-it and whee-wheeoo" by Hayman et al. (1986). The pattern of the Bristle-thighed's call resembles that of a Black-bellied Plover, but the quality is more strident and less plaintive. Many have noted that these whistles sound humanlike (D. Paulson pers. comm.). Marks and Redmond (1994a) also described a single noted "klee" call, and Peter Pyle (pers. comm.) remarked on a "jureeeee-jureeeee-jureee" call that resembles, in quality, the vocalizations of Long-billed Curlew (*Numenius americanus*). Many of the spring 1998 vagrants vocalized frequently, though some were quiet.

Habits. Witnesses of the 1998 spring invasion often commented on apparent differences in habitat and behavior between Whimbrels and the vagrant Bristle-thighed Curlews. One particularly dramatic behavior was that of whipping crabs. Some Bristle-thigheds seized crabs by the leg, then smashed them repeatedly into rocks or hard-packed sand with a whipping motion of the bird's head and neck. Some felt that this was to subdue the crab for access to its eggs (A. Jaramillo pers. comm.). The birds at the south jetty of the Columbia, however, grabbed crabs 2–5 cm in diameter and beat them until their carapaces were broken into small pieces and the interior flesh was well exposed, then eating it. This behavior is common among Bristle-thigheds with food items that are too large to be swallowed whole (Marks and Hall 1992). Remarkably, some Bristle-thigheds have learned to crack open albatross eggs by whipping stones into them with a similar motion (Marks and Hall 1992). Whimbrels, on the other hand, seem rarely to engage in such head and neck whipping, though Higgins and Davies (1996) described it.

Another comment was that the Bristle-thighed often walked in a crouched manner, somewhat like a rail (H. Nehls, M. Patterson pers. comm.). This action appears quite different from the usual movements of a Whimbrel.

There also appeared to be habitat differences. Whimbrels favor tidal flats along the coast, whereas the Bristle-thigheds shunned these and were most often found on beaches, at the base of jetties, and on grassy sand dunes. The birds along jetties walked among the rocks in search of prey. Though Whimbrels can sometimes be seen at these same locations, the difference between the two species' preferences seemed distinct.

Although these habitat and behavioral differences are not suitable for identification, they might serve well as a red flag, drawing attention to a vagrant.

We found several marks to be strongly suggestive but not fully conclusive. In spring, a brightly colored back and wings eliminate the Whimbrel, but the reverse is not necessarily true. A duller backed bird could be a Bristle-thighed in worn plumage. Flank barring and undertail covert markings typically are quite different but in the field may be difficult to discern and are not definitive. If the underparts are brightest on the flanks and undertail coverts, the bird is likely a Bristle-thighed Curlew, but the reverse is definitely not true. Upper primary pattern is quite useful in specimens and some photos, and may even be diagnostic, but field use is limited. Similarly, the under greater primary covert pattern also appears to be diagnostic but difficult to use in the field. The underprimary pattern will identify a Bristle-thighed or Whimbrel with about 90 to 95% accuracy and is also best assessed in specimens or fortuitous photographs. The Bristle-thighed's prey-slamming behavior appears to be quite unusual in Whimbrel and, if observed, would also point strongly but not absolutely to the Bristle-thighed.

Further features that may be useful but are only suggestive include underpart coloration, leg thickness, and toe thickness. Bill size and curvature, bill color, leg length, and underwing coloration are likely not useful.

SUMMARY

Between 26 April and 30 April 1998, at an elevation typical for migrating curlews, a highly unusual weather pattern prevailed over the central North Pacific—an anomaly associated with the West Pacific Oscillation, not El Niño. Shortly thereafter, between 13 and 17 Bristle-thighed Curlews were recorded from Point Reyes, California, to Tatoosh Island, Washington. These two events were likely linked. Any Bristle-thighed Curlews heading north between 26 April and 30 April 1998 would have encountered extremely strong headwinds, giving them the choice of continuing onward and facing the risk of running out of fuel or reorienting downwind in search of land. Such reorientation would have placed these birds on the North American coast between southern California and southernmost British Columbia with an arrival date between 28 April and 1 May.

The number of Bristle-thigheds that landed on the West Coast was undoubtedly greater than the number seen. Our estimates suggest that between 60 and 150 birds actually made landfall. Not unlikely, additional birds never made it to land, either by failing to reach the west coast or by continuing on into the storm. A significant portion of the small world population may well have been placed at risk by this anomalous weather.

Identification of the Bristle-thighed Curlew is complex. Few marks are absolutely reliable for identification, and previously published discussions have not been entirely accurate. The tail and rump remain the key, as in all plumages, the pattern and coloration of these areas consistently distinguish the Bristle-thighed Curlew from the Whimbrel. Even when the bird is on the ground, the tail pattern and color can usually be seen. The call of each species is diagnostic. The thigh bristles, if seen, eliminate the Whimbrel. The 1998 invasion proved to be a fine opportunity for birders to become familiar with Bristle-thighed Curlew identification. The prospect of future accurate reports of this species has certainly been enhanced.

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APPENDIX 1. Records of Vagrant Bristle-thighed Curlews in North America

Spring 1998: Adequately Supported

Floras Lake, Curry Co., Ore. (1); 6 May (D. Lauten, K. Castelein)
Ocean Shores, Grays Harbor Co., Wash. (2); 8 May (B. Sundstrom, H. Opperman)
South Jetty Columbia River, Clatsop Co., Ore. (3, photographed); 9–21 May (H. Nehls)
Ocean Shores, Grays Harbor Co., Wash. (1, photographed); 12–14 May (P. W. Smith)
Tatoosh Island, Clallam Co., Wash. (1); 13–15 May (R. Paine, T. Wooton)
Newport, Lincoln Co., Ore. (2, photographed); 13–15 May (E. Horvath)
Tatoosh Island, Clallam Co., Wash. (1, specimen); 14 May (R. Paine, T. Wooton)
Battery Point, Del Norte Co., Calif. (1, photographed); 14–16 May (A. Barron)
Point Reyes, Marin Co., Calif. (1, photographed); 16–25 May (C. and L. Lieurance, G. Griffeth)
Westport, Grays Harbor Co., Wash. (1); 18 May (G. Revelas)
Bandon Marsh/New River mouth, Coos Co., Ore. (1); 19–23 May (D. Lauten, K. Castelein, S. Brown)
Ocean Shores, Grays Harbor Co., Wash. (1–2, photographed); 20–24 May (D. Paulson)

Spring 1998: Inadequately Supported

Point Reyes, Marin Co., Calif. (2); 6 May
Humboldt Co., Calif. (1); 9 May
South Jetty Columbia River, Clatsop Co., Ore. (5); 14 May

Before 1998: Adequately Supported

Grant Bay, Vancouver I., B.C.; 30–31 May 1969 (Richardson 1970)
Bandon, Coos Co., Ore. (2); 16 September 1981 (Gilligan et al. 1994)
Leadbetter Point, Pacific Co., Wash.; 1 May 1982 (Widrig 1983)
Blackie Spit, along Boundary Bay, B.C.; 13–14 May 1983 (Campbell et al. 1990)

Before 1998: Inadequately Supported

Near Tofino, Vancouver I., B.C.; 1 September 1982 (Campbell et al. 1990)
Victoria, Vancouver I., B.C.; 11 September 1986 (K. Taylor pers. comm.)
Leadbetter Point, Pacific Co., Wash. (2); 18 May 1980 (Widrig 1983)

APPENDIX 2. Records of Vagrant Shorebirds from Western North America South of Alaska and Paralleling the Spring 1998 Irruption of the Bristle-thighed Curlew

The 1998 reports from California are all under review by the California Bird Records Committee; some may not be accepted. We, however, feel these reports are correct.

Gray-tailed Tattler
- Point Reyes, Marin Co., Calif.; 24–26 May 1998 (K. Hansen, S. N. G. Howell)
- Bodega Head, Sonoma Co., Calif.; 30 May 1998 (R. Rudesill)
- Princeton Harbor, San Mateo Co., Calif.; 6 June 1998 (A. Jaramillo)

Asiatic Whimbrel
- Ocean Shores, Grays Harbor Co., Wash.; 16 May 1987 (Paulson 1993)
- Ocean Shores, Grays Harbor Co., Wash.; 16 May 1998 (P. W. Smith)

Bar-tailed Godwit
- Ten previous spring records extending from 21 April to 10 June (Mlodinow and O'Brien 1996, NASFN 50:323).
- Ocean Shores, Grays Harbor Co., Wash.; 27 May 1998 (B. Shelmerdine)

Red-necked Stint
- Arcata, Humboldt Co., Calif.; 5 May 1969 (Harris 1996)
- Iona Island, Vancouver area, B.C.; 20 May 1997 (NASFN 51:914)

Sharp-tailed Sandpiper
- Leadbetter Point, Pacific Co., Wash.; 26 April 1979 (Mlodinow and O'Brien 1996)
- Lancaster, Los Angeles Co., Calif.; 5–9 May 1982 (Mlodinow and O'Brien 1996)
- Kern Natl. Wildlife Ref., Kern Co., Calif.; 8–10 May 1984 (Mlodinow and O'Brien 1996)
- Pescadero, San Mateo Co., Calif.; 14 May 1994 (Mlodinow and O'Brien 1996)