Waterbird Use of Bayland Wetlands in the San Francisco Bay Estuary: Movements of Long-billed Dowitchers during the Winter

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Abstract.—The San Francisco Bay estuary is a migration and wintering area for more than 1.5 million waterbirds on the west coast of North America. Because the estuary is located in a metropolitan area, development and diking of baylands (the region between the edge of the bay and the historical high tide line) have greatly altered the wetland landscape. Recently, conservation interests have promoted restoration of diked baylands to tidal salt marshes for the benefit of endangered native species. However, effects of tidal marsh conversion on the existing community of waterbirds in the baylands are largely unknown, especially in muted tidal marshes with restricted inflows and in artificial salt evaporation ponds where high waterbird densities are found. The first radio-marking study of the Long-billed Dowitcher (*Limnodromus scolopaceus*) was conducted in November-December 2000 to examine their use of baylands. We captured 32 birds by rocket netting in a muted tidal marsh on the North Bay and radio-marked them with 1.2 g transmitters affixed with glue. Individuals were tracked for an average of 20.3 d (±8.5 SD) and obtained 217 high tide and 195 low tide locations. Movements between tides ($\bar{x}$ = 1.29 ± 1.48 SD km) and home range sizes ($\bar{x}$ = 17.7 ± 16.0 SD km^2) were highly variable. Long-billed Dowitchers preferred open habitats such as muted tidal marshes during the high tide, but the majority (78.5%) also remained in these wetlands during low tide rather than feeding at nearby mud flats. Their avoidance of mud flats contrasted sharply with Western Sandpipers (*Calidris mauri*) but was similar to Black-necked Stilts (*Himantopus mexicanus*). Seven Long-billed Dowitchers flew 110 km inland to Central Valley wetlands in mid-December, a regional movement documented earlier for Dunlin (*Calidris alpina*) wintering on the coast. However, unlike Dunlin, their movements were not in response to rainfall but may have been in response to a low pressure front or possibly predictable flooding of fields in the Central Valley. Although the estuary is a major wintering area supporting large numbers of waterbirds, some birds such as Long-billed Dowitchers move inland to freshwater wetlands in the Central Valley.

Key words.—Long-billed Dowitcher, *Limnodromus scolopaceus*, radio telemetry, wintering ecology, San Francisco Bay.

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The area surrounding San Francisco Bay estuary is highly urbanized (Nichols *et al.* 1986), but it is still a site of hemispheric importance for shorebirds (Harrington and Perry 1995). San Francisco Bay supports a major proportion of shorebirds compared with other wetlands along the Pacific coast during the winter (Page *et al.* 1999). Many migratory species are found in the baylands (the area between the edge of the bay and the historical high tide line; Bay Conservation and Development Commission 1982; Bay Institute 1987) that comprise 858 km^2 of the estuary (Goals Project 1999). More than 90% of historical wetlands have been lost (Josselyn 1983), and the remaining bayland wetlands are diked and provide a fragmented landscape of non-tidal salt, brackish, and freshwater wetlands, agricultural lands, seasonal ponds, vernal pools, riparian scrub, and salt evaporation ponds (Goals Project 1999).

One of the most abundant species in the estuary during the winter is the Long-billed Dowitcher (*Limnodromus scolopaceus*). Long-billed Dowitchers breed in tundra regions from northeastern Russia to northwestern Canada (Takekawa and N. Warnock 2000). Their primary wintering range is along the Pacific and Gulf coasts of North America into Mexico. Long-billed Dowitchers are reported to frequent freshwater wetlands and small pools in salt marsh vegetation (Pitelka 1950; Cogswell 1977). Dowitchers are found in water over cobble, sand and mud on the Mad River of northern California (Colwell 1993) and in moderately to well-sorted fine sand areas on Bolinas Lagoon, California (Page *et al.* 1979). Although both Long-billed and Short-billed (*L. griseus*) Dowitchers use the San Francisco Bay estuary during the nonbreeding period, most birds in the region during the winter are Long-billed Dowitchers (Pitelka 1950; Takekawa and N. Warnock 2000).

The San Francisco Bay estuary is the most important wintering area for Long-billed Dowitchers on the Pacific Flyway of North America, but little is known about their site fidelity and habitat use in this estuary. Recent management in the estuary has focused on the vegetative aspects of tidal marsh restoration or recovery of target tidal wetland species, rather than on migratory waterbird habitats (Takekawa *et al.* 2001; see Warnock *et al.* 2002). Habitat information on site fidelity and habitat use is essential for determining effects of wetland management and appropriate scale, from site-specific to estuary-wide levels, that provide the greatest benefit for wintering shorebird populations. Thus, we used radio telemetry to examine the wintering movement and home range of Long-billed Dowitchers in the North Bay subregion. Differences in their movements and home range by age, week, and mass at capture were examined. Finally, their use of bayland wetlands and mud flats were compared with that of Western Sandpipers (*Calidris mauri*) and Black-necked Stilts (*Himantopus mexicanus*) to present differences evident in space use by representative shorebird species in the estuary.

STUDY AREA

Our intensive study area (37.90° to 38.25°N; 122.25° to 122.50°W) consisted of the North Bay subregion (Goals Project 1999) within the northern reach of the San Francisco Bay estuary of California (Fig. 1), while our extensive study area included the South, Central, and Suisun Bays and Delta of the Sacramento and San Joaquin Rivers (together known as the Bay-Delta region) and the Central Valley region of California. The North Bay subregion supports the second largest number of shorebirds in the estuary, only exceeded by the South Bay (Takekawa and S. Warnock 2000; Stenzel *et al.* 2002;). Tens of thousands of dowitchers, primarily Long-billed Dowitchers, are found in the estuary during the winter (Takekawa and S. Warnock 2000).

METHODS

We trapped 33 Long-billed Dowitchers with a 13 m × 20 m rocket net (Grubb 1988) between 15 November and 13 December 2000. Rocket netting was conducted in the West End Duck Club unit of the California Department of Fish and Game, Napa-Sonoma Marshes State Wildlife Area, a muted tidal marsh where full tidal action was restricted by a culvert (Fig. 1). One bird was captured in a mist net in Pond 1, a former salt evaporation pond in the Napa Sonoma Marshes State Wildlife Area. We determined the species (Takekawa and N. Warnock 2000), weighed, measured, and aged (AHY = after hatching year; HY = hatching year) birds (Takekawa and N. Warnock 2000) and fitted them with leg bands and radio transmitters (Holohil LB-2, 1.2 g, lifespan 40 d) glued onto their lower back (N. Warnock and S. Warnock 1993). The birds were released in the original capture area and were tracked on one low (<0.76 m) and one high (>1.3 m) tide each day in trucks with null-peak 4-element Yagi antenna and receiver systems with an average accuracy of 58 ± 35 SD m (Warnock and Takekawa 1995). Two or more bearings were taken within 15 minutes to minimize movement errors for each location, which was estimated from triangulation in a computer data entry program (Dodge and Steiner 1986). Nine aerial telemetry searches were conducted on 21, 30 November and 3, 7, 12, 17, 20, 26, and 31 December with a Cessna 172 (Ecoscan Telemetry, Watsonville, California) flying for 3-6 h at 650 to 2,500 m and fitted with twin 4-element Yagi antennas. The aerial search areas included the South, Central, and North Bays (21, 30 Nov.; 3, 7, 12 Dec.); Suisun Bay, the Sacramento River Delta, and Central Valley (3, 7, 12, 20, 26, 31 Dec.), and Bay and outer coast (20 Dec.).

Locations were plotted in a geographic information system (ArcView v. 3.2, ESRI, Redlands CA) on wetland coverages of the North Bay (San Francisco Estuary Institute, 2000) and the Central Valley (Teale Data Center, California Department of Fish and Game). When locations were obtained on successive tides within a day, we estimated mean movement distances for each bird by averaging the distances between consecutive low and high tide locations. We examined home range sizes but lacked the required sample size (>30 locations per bird) to use recent fixed kernel methods (Seaman *et al.* 1999). Cramer von Mises tests indicated that locations for most birds did not fit a bivariate normal distribution (Samuel and Garton 1985; Hooge and Eichenlaub 1997). Thus, we estimated 90% minimum convex polygon (MCP) home ranges and "core" use areas, defined as 50% MCP home ranges, for birds with ≥15 locations (see Warnock and Takekawa 1996) in the North Bay subregion. MCP home ranges were calculated in an extension to Arcview (Movement Analyst Extension v.2, Hooge and Eichenlaub 1997). Analysis of variance was used to examine differences in home range by age, mass, and week, and applied a linear regression model to examine the relationship between home range size and the mass of birds adjusted for structural size by dividing mass by diagonal tarsus length.

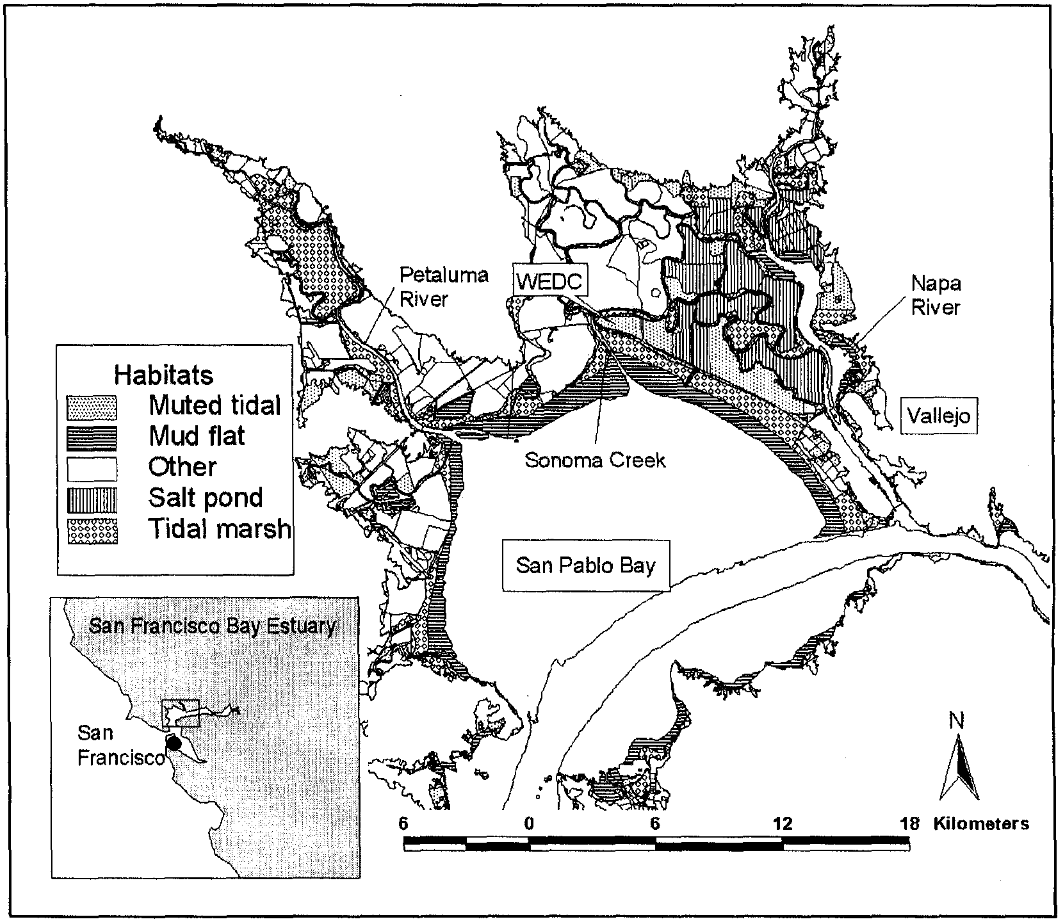

Figure 1. North Bay study area map showing diked baylands, mudflats, open water, salt ponds, and tidal marshes (San Francisco Estuary Institute 1998), as well as the trap site, West End Duck Club (WEDC).

Availability proportions (see Aebischer *et al.* 1993) for the six major habitat types (tidal marsh plain, salt pond, mud flat, agricultural land, seasonal wetland, and muted tidal marsh) where at least one Long-billed Dowitcher was located were estimated from existing coverages of the North Bay (San Francisco Estuary Institute 2000). Habitat use proportions were determined for birds with more than six locations in the major habitat types. We used all locations for those birds to examine habitat use, because we found few edge locations (<1%) that could be mistakenly attributed to another habitat type with our estimated location accuracy. Compositional analysis of log-transformed proportions was used to detect habitat preferences (Aebischer *et al.* 1993; Warnock and Takekawa 1995) and overall selection and age differences were tested with multivariate-analysis-of-variance (Wilk's λ: Johnson and Wichern 1988), followed by protected t-tests to locate significant differences.

RESULTS

We captured, radio-marked, and weighed 23 AHY ($\bar{x}$ = 100.3 ± 8.8 SD g) and 9 HY ($\bar{x}$ = 105.6 ± 13.5 SD g) Long-billed Dowitchers (Table 1) in seven different captures in November and December 2000. Individuals were tracked for up to 32 d but radio lifespan averaged 20.3 ± 8.5 SD d. A total of 412 locations were obtained for the 32 birds ($\bar{x}$ = 13.3 locations per bird) including 217 high tide and 195 low tide locations.

Local Movements

Average movement distance between high and low tides was estimated for each bird (Table 2), because the number of repeated samples between consecutive locations varied widely among individuals ($\bar{x}$ = 4.2 locations, range = 1-10). Movements by after hatching year (N = 17, $\bar{x}$ = 1.11 ± 0.76 SD km) and hatching year (N = 8, $\bar{x}$ = 1.59 ±

Table 1. Long-billed Dowitchers radio-marked in San Francisco Bay, 2000. Given are bird identification number, date radio-marked, age (AHY = after hatching year; HY = hatching year), mass (g), number of days the transmitter was active, and number of high tide (>1.3 m), low tide (<0.76 m), and total radio telemetry locations.

					Number of locations		
Bird	Date marked	Age	Mass (g)	Days active	High tide	Low tide	Total
5954	15 Nov	AHY	102	27	4	4	8
5972	30 Nov	AHY	103	1	1	1	2
5980	29 Nov	AHY	100	21	5	2	7
6009	29 Nov	AHY	99	15	9	5	14
6023	29 Nov	HY	89	28	1	2	3
6033	29 Nov	HY	111	22	11	11	22
6046	28 Nov	AHY	90	21	7	10	17
6059	29 Nov	AHY	97	9	5	2	7
6072	28 Nov	AHY	111	23	14	12	26
6082	13 Dec	HY	94	13	6	5	11
6096	29 Nov	AHY	90	21	4	2	6
6107	29 Nov	HY	125	29	17	10	27
6135	1 Dec	AHY	97	19	8	5	13
6146	13 Dec	HY	105	2	2	0	2
6157	28 Nov	AHY	110	22	8	4	12
6171	30 Nov	AHY	111	20	4	5	9
6182	29 Nov	HY	95	19	10	12	22
6199	1 Dec	AHY	99	30	10	15	25
6207	30 Nov	AHY	117	7	0	2	2
6223	30 Nov	AHY	113	7	2	3	5
6233	28 Nov	AHY	102	22	1	3	4
6245	28 Nov	HY	102	17	10	8	18
6258	29 Nov	HY	—	22	14	9	25
6282	30 Nov	AHY	107	15	6	8	14
6295	29 Nov	AHY	85	32	8	9	17
6304	1 Dec	AHY	94	30	8	7	13
6320	5 Dec	AHY	88	7	5	2	7
6330	13 Dec	HY	124	15	13	9	22
6344	28 Nov	AHY	96	29	13	9	22
6359	28 Nov	AHY	101	10	6	3	9
6373	30 Nov	AHY	98	20	8	4	12
6377	30 Nov	AHY	105	28	13	11	24

0.64 SD km) birds were not significantly different ($F_{1,23}$ = 2.68, n.s.). Overall, Long-billed Dowitchers flew an average of 1.29 ± 1.48 SD km between consecutive low and high tide locations (Table 2).

Regional Movements

Long-billed Dowitchers showed strong site fidelity to the North Bay (Fig. 2) and none of the radio-marked birds was relocated during flights of the South, Central, or Suisun Bays. However, seven birds moved 110 km inland from the North Bay to the Central Valley (Fig. 3). They were last detected in daily ground searches in the North Bay between 6-13 December (Fig. 4a) and were located in the Central Valley across a south-to-north band 293 km wide from the South Grasslands Water District in the San Joaquin Valley to the Delevan and Colusa National Wildlife Refuges in the Sacramento Valley. The timing of their movements showed little relationship to rainfall in the Bay-Delta and the Central Valley as precipitation fell prior to and following their departure from the North Bay, but not during that period (Fig. 4b). Instead, their departure seemed to be subsequent to the movement of a ridge of low pressure passing through the region (Fig. 4c).

Table 2. Local movements of radio-marked Long-billed Dowitchers in San Francisco Bay, 2000. Given are bird identification number, mean intertidal distance (km) between consecutive low and high tides, and 90% minimum convex polygon (MCP) home ranges and "core" areas defined as 50% MCP home ranges for birds with ≥15 locations (see Table 1). Grand means, standard deviation, and sample sizes are reported for all birds for intertidal distance, home range, and core area.

Bird	Mean intertidal distance (km)	Home range (km^2)	Core area (km^2)
5954	3.30	—	—
6009	0.89	—	—
6033	0.81	1.53	0.21
6046	1.24	7.74	0.28
6059	0.62	—	—
6072	0.52	0.60	0.10
6082	1.85	—	—
6107	1.58	4.37	0.21
6135	0.50	—	—
6157	0.54	—	—
6171	2.18	—	—
6182	1.55	6.85	0.18
6199	1.57	14.77	0.59
6223	0.61	—	—
6245	1.63	1.12	0.08
6258	1.18	1.38	0.12
6282	0.71	—	—
6295	0.53	26.63	0.32
6304	0.49	—	—
6320	1.45	—	—
6330	2.95	35.89	0.80
6344	0.67	1.25	0.09
6359	1.28	—	—
6373	0.85	—	—
6377	2.04	6.16	0.69
Mean	1.29	9.02	0.31
SD	1.48	11.32	0.25
N	25	12	12

Home Range Size

Home range size (Table 2) was highly variable ($\bar{x}$ = 9.0 ± 11.3 SD km^2). We calculated core areas as 50% minimum convex polygons and found that birds used very small areas ($\bar{x}$ = 0.31 ± 0.25 SD km^2) in the center of their home range (Fig. 5). No difference was detected ($F_{1,10}$ = 0.13, n.s.) in home range size between AHY (N = 6, $\bar{x}$ = 15.2 ± 17.3 SD km^2) and HY (N = 6, $\bar{x}$ = 12.7 ± 12.7 SD km^2). Home range size for all birds combined varied widely from 21.9 km^2 to 239 km^2 among weeks of the winter, but we found no obvious trend ($F_{1,3}$ = 2.47, n.s.). Home range size seemed to decrease with increasing body mass, but the null hypothesis was not rejected ($F_{1,8}$ = 3.91, P = 0.08).

Baylands Habitat Use

Long-billed Dowitchers used bayland wetlands during high tides when mud flats were inundated, but the majority (79%) of their low tide locations also were in bayland wetlands when mud flats were available. Overall availability of habitats in the North Bay study area (Fig. 6) included tidal marsh plain (28%), salt pond (21%), mud flat (18%), agricultural land (12%), seasonal wetland (12%), and muted tidal marsh (9%). Their habitat use was not in proportion to availability (Wilk's λ = 0.05, $F_{5,20}$ = 74.9, P < 0.0001), because they used muted tidal marsh seven times more than expected (64%) followed by tidal marsh plain (20%), mud flat (10%), agricultural land (3%), salt pond (2%), and seasonal wetland (0.5%). Habitat use by AHY and HY birds was different (Wilk's λ = 0.05, $F_{5,20}$ = 74.9, P < 0.0001) as HY birds used muted tidal marsh less and tidal marsh plain more than AHY birds (Table 3). Long-billed Dowitchers selected mud flats as the second-ranked habitat after muted tidal marsh at low tide, but at high tide when mud flats were unavailable, their preference for the remaining habitats was similar (Table 3).

DISCUSSION

These results from radio-marked Long-billed Dowitchers support findings on Western Sandpipers, Black-necked Stilts, Greater Scaup (*Aythya marila*) and Lesser Scaup (*A. affinis*) that indicate waterbirds in the San Francisco Bay estuary have strong site fidelity within North and South Bay subregions (Warnock and Takekawa 1995, 1996; C. Hickey, N. Warnock, and J. Takekawa, unpublished data; J. Takekawa, unpublished data). A general picture is emerging that indicates wintering waterbirds rarely move among subregions in the estuary within the winter, but remain in a single bay or local area. The implications of these findings are

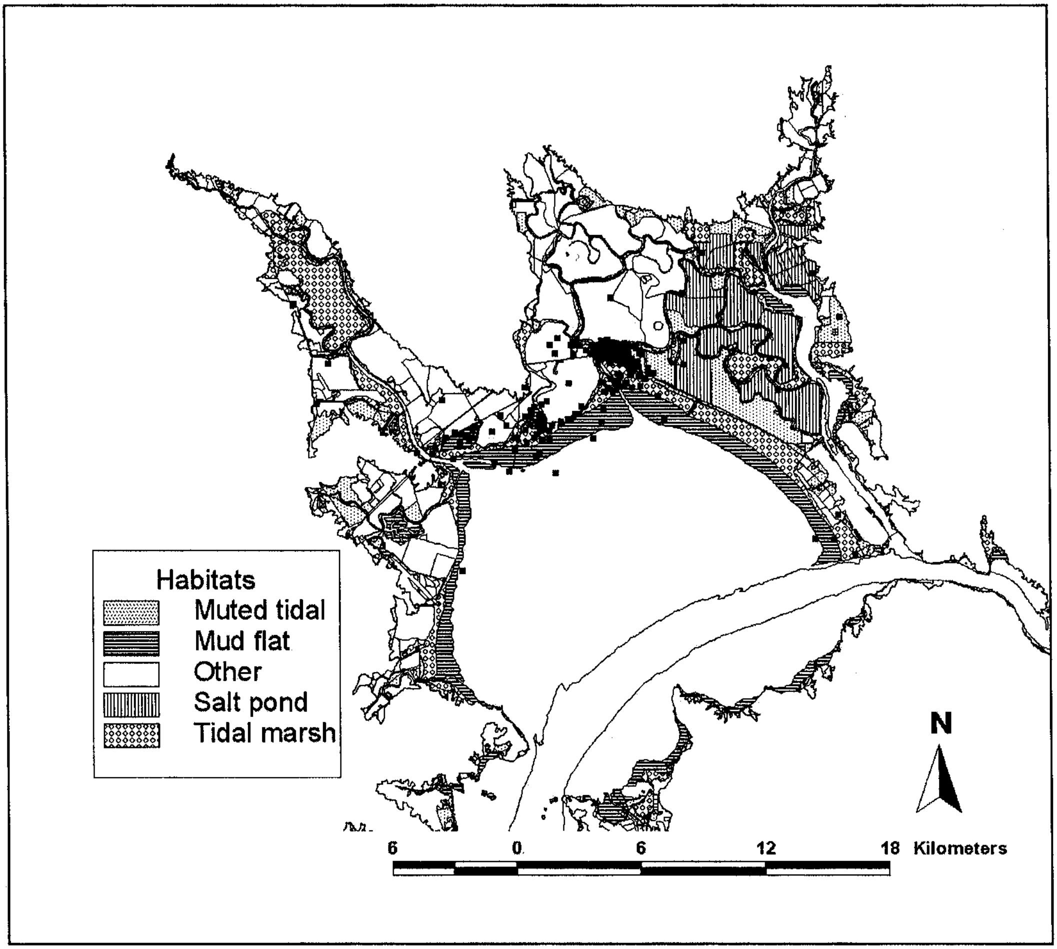

Figure 2. Distribution map of total locations for 32 radio-marked Long-billed Dowitchers captured on the northern edge of the North Bay subregion of the San Francisco Bay estuary from 15 November 2000 to 13 December 2000 and followed for up to 32 days.

that management for waterbirds in the estuary should occur at a subregional level. Mitigation of wetland habitat in one subregion will not suffice for loss of habitat in a different subregion for most waterbirds.

Local Movements

Some shorebird species have daily movements of up to 25 km (Myers 1986, Ruiz *et al.* 1987). In contrast, adult and first-year Western Sandpipers moved an average distance of 2.2 km in the South Bay (Warnock and Takekawa 1996), and our results showed even smaller movement between roosting and feeding areas for Long-billed Dowitchers, averaging 1.3 km distance between locations on consecutive tides. However, movements of Black-necked Stilts in the North Bay were even more restrictive and averaged only 0.2 km per day and only 4.5 km from breeding to post-breeding areas (C. Hickey, N. Warnock, and J. Takekawa, unpublished data).

Regional Movements

Earlier surveys showed that shorebirds disappeared from coastal areas during rainy periods and suggested interchange with the Central Valley (Shuford *et al.* 1989; Warnock *et al.* 1995; Shuford *et al.* 1998). Our study confirmed that birds captured in North Bay during the winter moved inland to the Central Valley, distributed from the South Grasslands

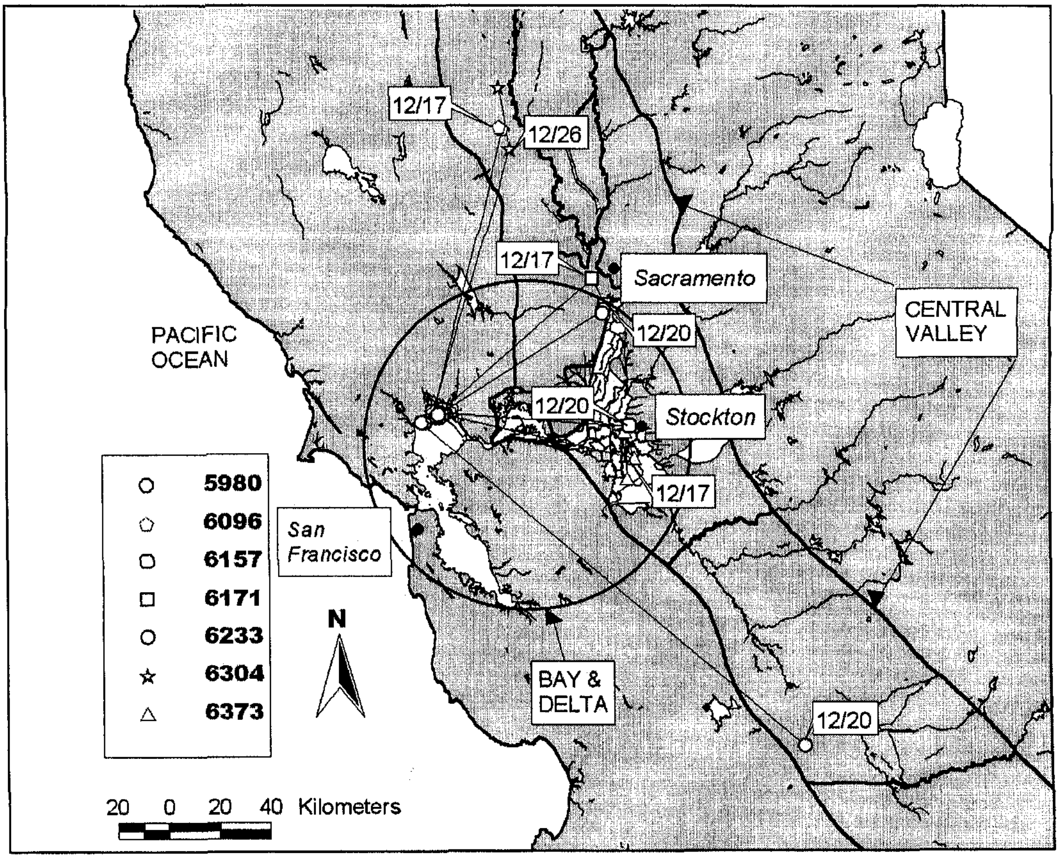

Figure 3. Movements of Long-billed Dowitchers from the North Bay subregion of the San Francisco Bay estuary to the Central Valley of California, December 2000. Dates associated with locations indicate when birds were detected in aerial telemetry surveys.

Water District to Sacramento National Wildlife Refuges (Fig. 3). We observed similar movements of radio-marked Canvasback Ducks (*Aythya valisneria*) from the North Bay to the Central Valley in December and January 2000-2001 (J. Takekawa, unpublished data).

Warnock *et al.* (1995) analyzed an extensive dataset and reported that the stimulus for the non-migratory movements of Dunlin (*Calidris alpina*) from the coast to the Central Valley was winter rains, and that the two most plausible explanations for these movements were deteriorating conditions in coastal wetlands or increased inland habitats. In our single-year study of radio-marked Long-billed Dowitchers, rainfall in the estuary or Central Valley was not correlated with their regional movements and occurred mainly after birds departed from the North Bay (Fig. 4). We found that a low-pressure front directly preceded their departure, which may suggest weather fronts, an important aid for migrating shorebirds (Butler *et al.* 1997), are a proximate cue for their regional movements. Kelly *et al.* (2002) found a slight but significant increase in Dunlin body mass with decreasing barometric pressure but found movements correlated with rainfall rather than barometric pressure. In a study by Elphick and Oring (1998), most dowitchers were found in flooded rice fields of the Central Valley, and these fields typically are flooded for hunting in October through December. Thus, in addition to weather cues, their regional movements may be related to water management practices in the Central Valley that improve inland habitat conditions for shorebirds.

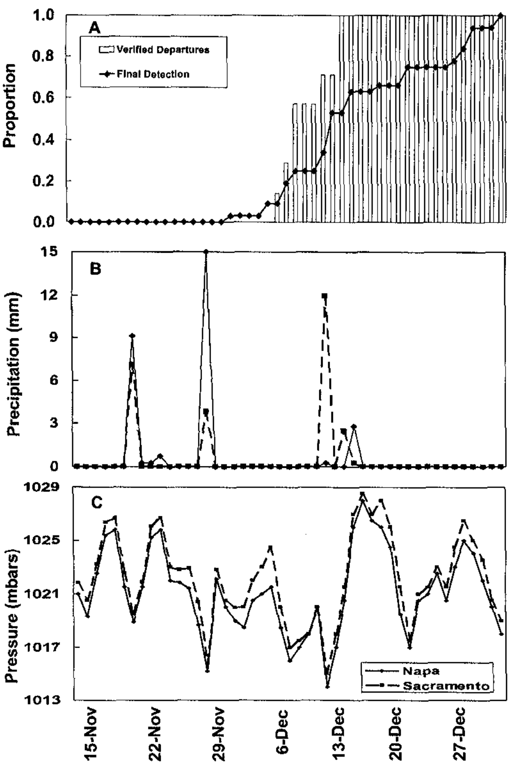

Figure 4. From top to bottom, (A) cumulative proportion of radio-marked Long-billed Dowitchers verified departing from the north San Francisco Bay estuary to the Central Valley in December 2000 on the basis of daily telemetry ground searches and proportion of radio-marked birds last detected in searches; (B) daily precipitation (mm); and (C) barometric pressure (mbars) readings from Napa (North Bay: solid line) and Sacramento (Central Valley: dashed line) airports.

Our results indicated strong site fidelity while the Long-billed Dowitchers remained within the estuary as none of the birds moved to the Central Bay or South Bay where most dowitchers are found (Stenzel *et al.* 2002). None of the 105 radio-marked Western Sandpipers was located outside of the South Bay subregion where they were captured (Warnock and Takekawa 1996) until the spring migration when many were relocated in Alaska (Iverson *et al.* 1996; Warnock and Bishop 1998). Similarly, only three of 59 Black-necked Stilts marked in the North or South Bay moved to a different subregion (C. Hickey, N. Warnock, and J. Takekawa, unpublished data). These results show consistent patterns of site fidelity at a subregional scale for shorebirds in the estuary.

Home Range and Core Areas

We used a different measure of home range and core areas (MCP) for Long-billed Dowitchers than was used for Western Sandpipers (bivariate ellipse: Warnock and Takekawa 1996) and Black-necked Stilts (fixed kernel: C. Hickey, N. Warnock, and J. Takekawa, unpublished data) because of the different sample sizes. However, location accuracy was similar in each of these studies because we used the same telemetry systems and procedures. The number of locations per marked individual was similar to the Western Sandpiper study (Warnock and Takekawa 1995, 1996) but half of the number per individual for Black-necked Stilts which carried transmitters that lasted twice as long. Smaller numbers of locations typically result in larger, rather than smaller home range sizes we observed in Long-billed Dowitchers. The home range size of Long-billed Dowitchers ($\bar{x}$ = 17.7 km^2) was similar to Western Sandpipers ($\bar{x}$ = 22 km^2), but HY Western Sandpipers (26.6 km^2) had larger home ranges than adults (17.2 km^2) and their home ranges were of similar size in early winter, mid winter, and spring (Warnock and Takekawa 1996; Takekawa and S. Warnock 2000).

Despite similar home range sizes, core areas for Western Sandpipers ($\bar{x}$ = 9.5 km^2: 43% of total) were much larger than core areas for Long-billed Dowitchers ($\bar{x}$ = 0.31 km^2: <2% of total). The extremely small core area used by Long-billed Dowitchers suggested that they were more selective than Western Sandpipers in their use of high tide habitats, which were primarily shallow pools adjacent to or surrounded by vegetated areas. Page and Whitacre (1975) estimated that 16% of dowitchers wintering at Bolinas Lagoon, California were killed by raptors. Long-billed Dowitchers may be selecting roosting areas near vegetation cover to avoid predation. In contrast, Black-necked Stilts in both South and North Bays had even smaller home range areas of 3.6 km^2 (C. Hickey, N. Warnock, and J. Takekawa, unpublished data) but had multiple centers of activity or roosting areas.

Birds with smaller home ranges may use nearby foraging sites, maximizing their ener-

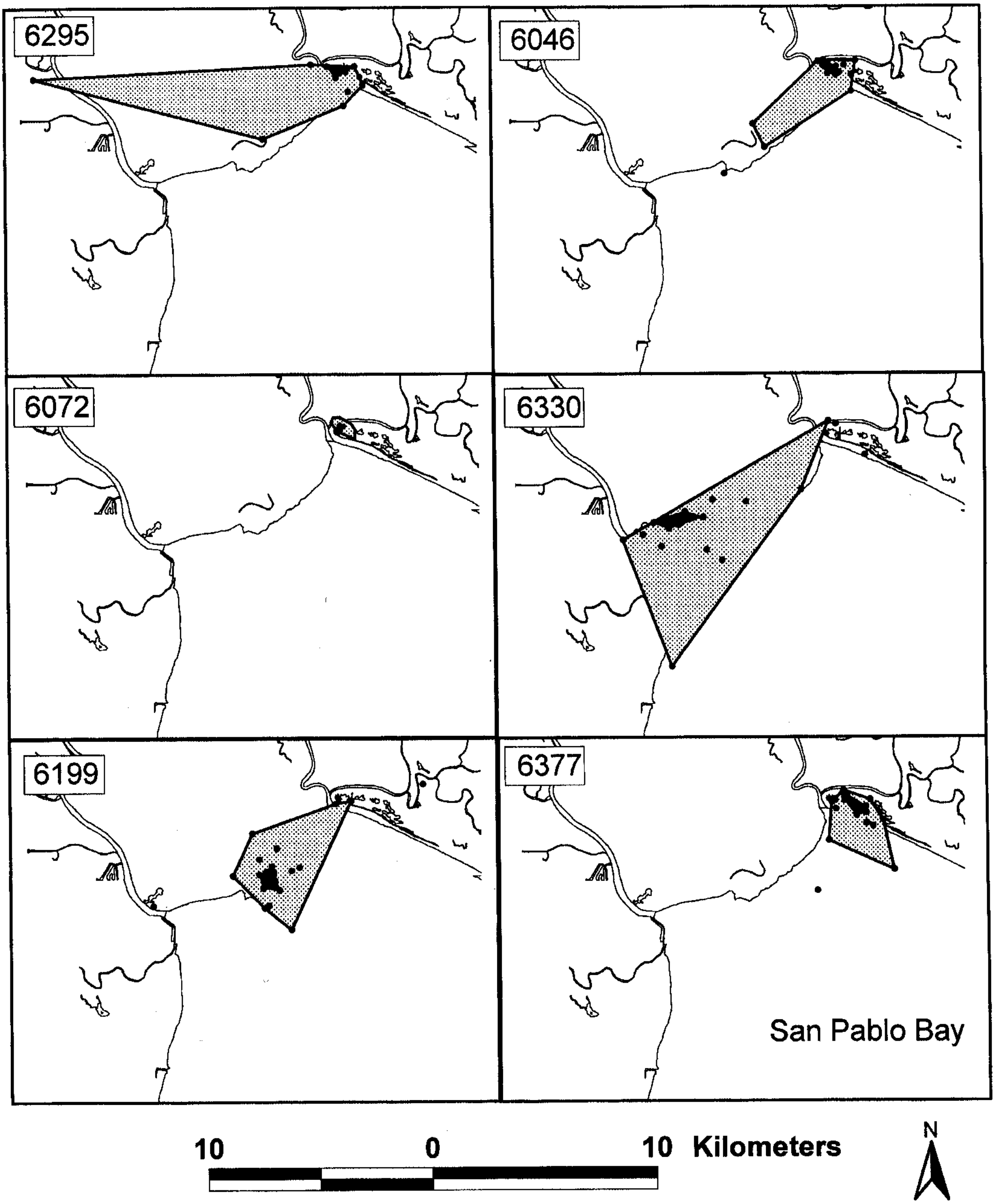

Figure 5. Examples of individual variation in home range sizes (90% minimum convex polygon) and "core" areas (50% minimum convex polygon) for six selected Long-billed Dowitchers radio-tracked during the winter (November-December 2000).

gy gains while minimizing their acquisition costs. Thus, we would expect them to have better body condition as evidenced by their greater body mass. However, only a weak (nearly significant) relationship was found between home range size and body mass at capture with our small dataset.

Bayland Habitat Use

Unlike the Central Valley (Shuford *et al.* 1993), where most (66%) dowitchers are found in managed wetlands rather than in sewage or evaporation ponds (3%), our studies showed Long-billed Dowitchers were

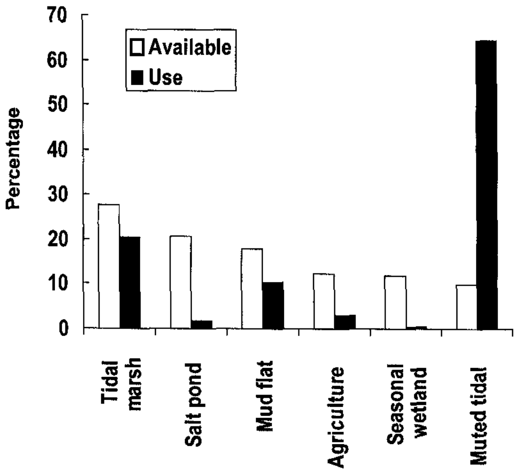

Figure 6. The proportion of habitats in the North Bay subregion of the San Francisco Bay estuary available and used by radio-marked Long-billed Dowitchers during the winter (November-December 2000). Six major habitat types included tidal marsh plain, salt pond, mud flat, agricultural land, seasonal wetland, and muted tidal marsh (areas where culverts or restrictions reduced full tidal flow).

found feeding and roosting in muted tidal impoundments and salt pond habitats with large expanses of unvegetated areas (Fig. 6). Similarly, dowitchers on the U.S. east coast were reported in freshwater impoundments, especially those with little vegetation and salt pans (Tomkins 1961; Veit and Petersen 1993).

However, the largest counts of dowitchers in San Francisco Bay (9,400-22,400) have been reported in mud flats of the South Bay, and the second highest survey area (3,300-9,400) includes mud flats of the North Bay (1988-1992: summarized in Takekawa and S. Warnock 2000) which includes the largest mud flat area in the entire estuary (San Francisco Estuary Institute 2000; Stenzel *et al.* 2002). In contrast, the birds tracked in this study were rarely found on mud flats. Most birds in that habitat were located, and it is unlikely that local movements were affected because at least seven individuals moved to the Central Valley.

Dowitchers may have foraged on mud flats at night when we were not tracking. In the only nocturnal studies on the species, Dodd and Colwell (1996) found that few dowitchers foraged at night in northern California during the winter. Some of our observations were before dawn or after dusk, but no differences in distribution were found. Birds may have responded to lack of food in the mud flats. Invertebrates may have declined severely following the El Niño and La Niña events of 1997-1999. For example, extremely low densities of clams (*Potamocorbula amurensis* and *Macoma balthica*) were found in the North Bay in the spring of 2000 (Poulton *et al.* 2002) that suggested poor productivity a few years earlier. Thus, reduced invertebrate availability may be an explanation for limited use of mud flats. However, the most feasible explanation was that the shallow mud flats created in the West End Duck Club after tidal action was restored recently provided excellent habitat for shorebirds. Tidal exchange increased in this unit when culverts were opened in the early 1990s.

Visual observations indicated that Long-billed Dowitchers were not only roosting but also foraging in the bayland habitats, especially the muted tidal ponds, during the low and high tides. Use of the muted tidal marshes was primarily in areas without vegetation, or in pools between vegetated areas. The habitat use of Long-billed Dowitchers contrasted with Western Sandpipers that preferred tidal sloughs and mud flats on low tides and salt-pond levees at high tides (Warnock and Takekawa 1995). Long-billed Dowitchers' space use was more similar to postbreeding Black-necked Stilts which used similar areas on low and high tides (C. Hickey, N. Warnock, and J. Takekawa, unpublished data) and remained in freshwater marshes or moved between salt ponds and muted tidal marshes.

Conservation and Management of Baylands for Shorebirds

One of the most important unvegetated habitats in the baylands is the salt evaporation ponds (see Warnock *et al.* 2002). However, many conservation groups propose conversion of these wetlands to tidal salt marshes, and only a few hundred hectares of the more than ten thousand hectares of salt ponds in the estuary will likely remain through the next century (Goals Project

Table 3. Habitat preferences of 25 radio-marked Long-billed Dowitchers located in six major habitat types of the North Bay subregion of San Francisco Bay, 2000. Compositional analysis (Aebischer *et al.* 1993) was used to determine rank order and test for significant preferences. Preferences are ranked in descending order of preference where "1" is the most preferred. Ranks with superscript letters that are the same indicate habitat types that were not significantly different. A multivariate analysis of variance test showed differences in habitat preferences (Wilks' λ = 0.036, $F_{2,23}$ = 16.1, $P < 0.0001$) by age (AHY = after hatching year; HY = hatching year). Ages were grouped to examine differences by tide level (high >1.3 m; low <0.76 m), when mud flats were inundated and unavailable. Preferences on low and high tides were not compared directly because mud flats were inundated and unavailable on high tides.

	Habitat Rank					
Comparison	Tidal marsh plain	Salt pond	Mud flat	Agricultural land	Seasonal wetland	Muted tidal marsh
Age						
AHY	3^{A}	5^{BC}	2^{A}	4^{B}	6^{BC}	1
HY	2^{AB}	5^{DE}	3^{BC}	4^{CD}	6^{E}	1^{A}
Tide						
Low tide	3^{AB}	5^{AC}	2^{BC}	4^{AD}	6^{CD}	1
High tide	2	5	—	3^{A}	4^{A}	1

1999). Although our radio-marked sample of dowitchers preferred the muted tidal marsh where they were captured, surveys in the former salt ponds of the Napa-Sonoma Marshes State Wildlife Area showed large numbers of deep probers, primarily Long-billed Dowitchers (Takekawa *et al.* 2001) that were twice as high as the densities in other bayland wetlands. Unvegetated habitats in tidal areas that are used by Long-billed Dowitchers are dynamic and require storms or flooding to impede vegetation colonization but will be replaced by a static marsh plain if water levels in the areas are engineered for restoration of Cord Grass (*Spartina foliosa*) and Pickleweed (*Salicornia virginica*).

In addition, proposed widespread changes in the composition of bayland wetlands of the San Francisco Bay estuary (Goals Project 1999) may greatly alter the current distribution and abundance of Long-billed Dowitchers. The recent Calfed Ecological Restoration Program will greatly increase the abundance of tidal wetlands in the North Bay, Suisun, and Delta. Proposed conversion of salt ponds to tidal marshes will decrease total bayland area preferred by Long-billed Dowitchers in both the North and South Bay subregions. Thus, habitat compensation for altering the wetland habitats that are currently used by species such as Long-billed Dowitchers should be mitigated in adjacent areas of the same subregion, and tidal marsh restorations should include beneficial design elements such as roosting islands or wide channels with mud flats for foraging.

Finally, the strong site fidelity we found in Long-billed Dowitchers may make them more vulnerable to point source contamination in this highly urbanized estuary. Site-specific differences have been documented in elevated contaminant concentrations of Long-billed Dowitchers in the South Bay (Hui *et al.* 2001). The North Bay subregion was the main deposition site of hydraulic mining debris from the Sierra Nevada gold rush period of 1849. Extensive wetland restoration projects may mobilize mercury through methylation (Marvin-DiPascuale *et al.* 2002) that may pose a significant risk to species that use these areas as foraging sites.

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