Research Article

Pintail and Mallard Survival in California Relative to Habitat, Abundance, and Hunting

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ABSTRACT The influence of habitat, waterfowl abundance, and hunting on winter survival of waterfowl is not well understood. We studied late August–March survival of 163 after-hatch-year (AHY) and 128 hatch-year (HY) female mallards (*Anas platyrhynchos*) radiotagged in Sacramento Valley (SACV) and 885 AHY female northern pintails (*A. acuta*) radiotagged throughout the Central Valley of California, USA, relative to flooded habitat (HAB), January abundance of each species (JMAL or JPIN), hunter-days (HDY), and a hunting pressure index (HPI) that combined these variables. From EARLY (1987–1994) to LATE (1998–2000), HAB increased 39%, JPIN increased 45%, JMAL increased 53%, HDY increased 21%, duck-hunting season increased from 59 days to 100 days, and the female daily bag limit doubled to 2 for mallards but remained 1 for pintails. Survival (± SE) was greater during LATE versus EARLY for pintails radiotagged in each region (SACV: 93.2 ± 2.1% vs. 87.6 ± 3.0%; Suisun Marsh: 86.6 ± 3.2% vs. 77.0 ± 3.7%; San Joaquin Valley: 86.6 ± 3.1% vs. 76.9 ± 4.1%) but not for SACV mallards (AHY: 70.6 ± 7.2% to 74.4 ± 7.7% vs. 80.1 ± 7.2% to 82.8 ± 5.6%; HY: 48.7 ± 9.1% [1999–2000 only] vs. 63.5 ± 8.8% to 67.6 ± 8.0%). Most pintail (72%) and mallard (91%) deaths were from hunting, and lower HPI and higher JPIN or JMAL were associated with reduced mortality. Increased HAB was associated with reduced winter mortality for pintails but not for SACV mallards. Pintail survival rates that we measured were within the range reported for other North American wintering areas, and during LATE were higher than most, even though our study duration was 68–110 days longer. Winter survival rates of SACV mallards were also within the reported range. However, with higher bag limits and longer seasons, mallard survival during LATE was lower than in most other wintering areas, especially during 1999–2000, when high winds on opening weekend resulted in high hunting mortality. Habitat conservation and favorable agriculture practices helped create a Central Valley wintering environment where natural mortality of mallards and pintails was low and survival varied with hunting mortality. We recommend regulations and habitat management that continue to minimize natural mortality while allowing sustainable harvest at a level that helps maintain strong incentive for management of Central Valley waterfowl habitats, including the large portion that is privately owned. (JOURNAL OF WILDLIFE MANAGEMENT 71(7):2238–2248; 2007)

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The Central Valley of California (Fig. 1), USA, is one of the most important waterfowl wintering areas in the world (Bellrose 1980, Gilmer et al. 1982). Half or more of the northern pintails (*Anas acuta*; hereafter pintail) in North America migrate to and winter in California, arriving as early as the first week of August and remaining through March (Bellrose 1980, Austin and Miller 1995). Despite a 75% decline in their North American breeding population since the 1970s, pintails remain the most abundant waterfowl species wintering in the Central Valley (U.S. Fish and Wildlife Service [USFWS] 2005, 2006). Mallards (*A. platyrhynchos*) are less than half as abundant as pintails during winter in California. However, with the decline of pintails and diverging bag limits for the 2 species (D. Yparraguirre, California Department of Fish and Game [CDFG], unpublished data), mallards surpassed pintails as the top-ranked species in the California harvest every year since 1986 (Carney et al. 1975, Trost and Drut 2003).

Factors that affect the wintering environment for waterfowl in the Central Valley, including habitat availability, waterfowl population size, and hunting pressure, changed during 1987–2000. In 1990, the Central Valley Joint Venture (CVJV) began to restore and enhance wetland and agricultural habitats (CVJV 2006), and several new national wildlife refuges (NWRs), state wildlife areas (WAs), and nongovernmental preserves were soon established (Fig. 1). In addition, the California Rice Straw Burning Reduction Act of 1991 (Assembly Bill 1378) mandated a gradual phase-out of rice straw burning (Hill et al. 1999), and farmers increased postharvest flooding of fields. Overall, flooded habitat in the Central Valley increased 39% from 1987–1990 to 1998–2000, with postharvest flooding of rice in the Sacramento Valley (SACV) accounting for most of the increase (Table 1). Thus, the extent and distribution of waterfowl habitat in the Central Valley during 1987–1994 (EARLY period) when these habitat changes began to occur was quite different from that during 1998–2000 (LATE period) after these habitat changes were in place.

Wintering waterfowl abundance, harvest regulations, and hunter effort in the Central Valley also changed during 1987–2000. Pintails increased 45% and mallards increased 55% during winter in the Central Valley between EARLY

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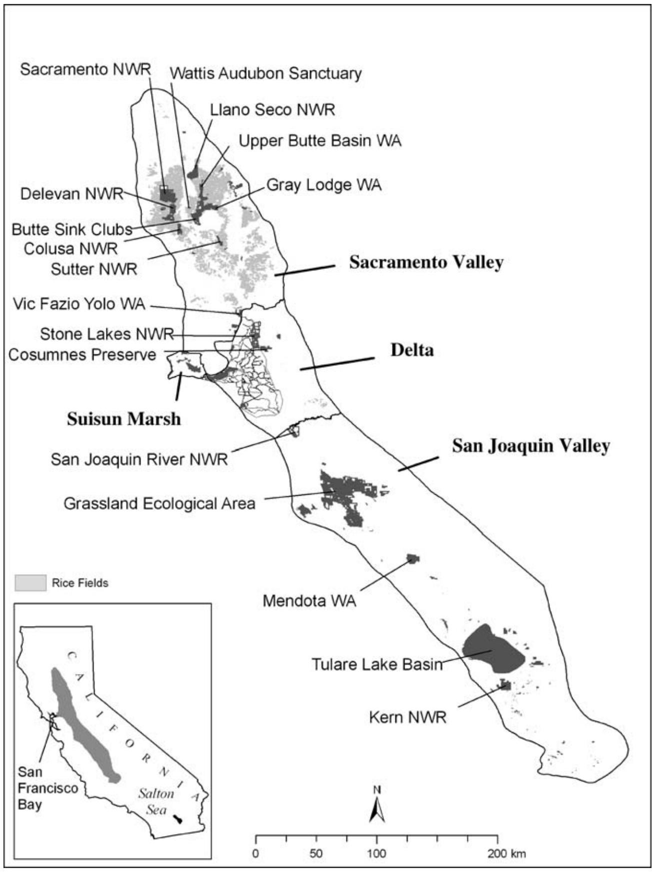

Figure 1. National wildlife refuges (NWRs), state wildlife areas (WAs), and other important waterfowl habitat areas within the major regions (Sacramento Valley, San Joaquin Valley, Delta, and Suisun Marsh) of the Central Valley of California, USA, during 1987–2000. Grizzly Island and Island Slough WAs in Suisun Marsh, and San Luis and Merced NWRs and Los Banos, Volta, and North Grasslands WAs in the Grassland Ecological Area are not identified. Areas added during 1990–1997 include Llano Seco NWR, Upper Butte Basin WA, Wattis Audubon Sanctuary, Vic Fazio Yolo WA, Stone Lakes NWR, Consumnes Preserve, San Joaquin River NWR, new units in the Grassland Ecological Area (Arena Plains and North units of Merced NWR, Bear Creek units of San Luis NWR, and the Gadwall Unit of Los Banos WA), and new units of Mendota WA.

and LATE (Table 2). Managers adjusted regulations in response to changing continental breeding populations. For mallards, managers increased the daily bag limit from 3 or 4 with $\leq$1 female during EARLY to 7 with $\leq$2 females during LATE. For pintails, managers kept the daily limit at 1 of either sex during both periods, except in 1987, when the pintail limit was 4 with $\leq$1 female (D. Yparraguirre, unpublished data). Managers set the hunting season length at 79 consecutive days in 1987 but during the rest of EARLY shortened it to 59 days with a 22-day to 23-day first season (hunt1) and a 36-day to 37-day second season (hunt2) starting after an 11-day to 27-day closure (split). During LATE, they increased the season to 100 consecutive days and added a junior hunter weekend after hunt2 (D. Yparraguirre, unpublished data). Also, during LATE, hunters initially and increasingly used spinning-wing decoys (Ackerman et al. 2006). Central Valley duck hunters hunted 360,800–531,500 ($\bar{x} \pm$ SE = 463,400 $\pm$ 29,600) days (hunter-days [HDY]) during EARLY and 391,800–733,600 (562,700 $\pm$ 170,900) days during LATE (Table 3).

Table 1. Average annual area (km^2) of managed wetland and flooded agricultural in California's Central Valley, USA, regions during 1987–1990, 1991–1994, and 1998–2000.[a]

Habitat and yr	Sacramento Valley	Delta	Suisun Marsh	San Joaquin Valley	Central Valley total
Wetland					
1987–1990	162	13	153	257	585
1991–1994	168	15	153	263	599
1998–2000	256	26	153	315	750
Agriculture					
1987–1990	537	95	0	47	679
1991–1994	623	133	0	32	788
1998–2000	847	128	0	31	1,006
Combined					
1987–1990	699	108	153	304	1,264
1991–1994	791	148	153	295	1,387
1998–2000	1,102	155	153	346	1,756

[a] Data from Fleskes et al. (2005*a*).

Effective management of waterfowl requires an understanding of factors that affect their winter survival (USFWS and Canadian Wildlife Service 1986, Reynolds et al. 1995). Although inadequate recruitment is probably the main cause of the long-term pintail decline in North America (Miller and Duncan 1999), female survival is also important in pintail population dynamics (Flint et al. 1998), and past increases were associated with high female survival (Hestbeck 1993*b*). Female pintails exhibit high fidelity to the Central Valley in winter (Rienecker 1987*a*, Hestbeck 1993*a*), and high mortality may reduce viability of local populations (Hestbeck 1993*a*). Thus, female mortality on wintering areas could be an important determinant of pintail population trends. The breeding population of mallards in California has been fairly stable for over a decade despite significant habitat improvements (D. Yparraguirre, unpublished data). Thus, knowledge of how winter survival of female mallards has changed over time also is needed to guide their management. To address these issues, we modeled late August–March survival of radiotagged female pintails and mallards in the Central Valley of California during EARLY and LATE relative to wintering habitat, winter population size, and hunter-days.

STUDY AREA

The Central Valley of California is comprised of SACV in the north, San Joaquin Valley (SJV) in the south, and Suisun Marsh (SUISM) and Sacramento–San Joaquin River delta (DELTA) east of San Francisco Bay (Fig. 1; USFWS 1978). Central Valley waterfowl habitat during 1987–2000 varied among years and regions (Table 1). Dry to extreme drought conditions prevailed during EARLY, with low availability of water restricting fall flood-up of managed wetlands except in 1993–1994 and little winter-rain flooding except in 1992–1993 (Fleskes et al. 2005*b*). Good availability of water during LATE allowed all managed

Table 2. Abundance (thousands) of northern pintails and mallards in California's Central Valley, USA, regions recorded during early January aerial surveys in years when each species' survival was studied with radiotelemetry,[a] 1987–2000.

Species and yr	Sacramento Valley	Delta	Suisun Marsh	San Joaquin Valley	Central Valley total
Pintail					
1987–1988	996.7	7.3	7.2	41.4	1,052.7
1988–1989	464.9	10.0	14.7	32.4	521.9
1989–1990	565.4	43.3	48.8	47.2	704.7
1991–1992	518.2	20.8	22.5	13.4	574.9
1992–1993	446.2	57.2	13.6	111.6	628.5
1993–1994	829.5	26.6	8.6	35.5	900.3
1998–1999	814.3	38.2	6.7	63.6	922.9
1999–2000	891.1	77.8	45.8	200.9	1,215.6
Mallard					
1988–1989	214.4	5.5	6.2	16.6	242.8
1989–1990	196.7	15.3	15.8	18.6	246.5
1998–1999	359.1	22.7	7.1	16.2	405.1
1999–2000	279.1	8.8	12.2	54.8	354.9

[a] Data from U.S. Fish and Wildlife Service (1988, 1989, 1990, 1992, 1993, 1994, 1999, 2000).

Table 3. Duck hunter-days (thousands) in California's Central Valley, USA, regions for years when female northern pintail or mallard survival was studied with radiotelemetry,[a] 1987–2000.

Yr	Sacramento Valley	Delta	Suisun Marsh	San Joaquin Valley	Central Valley total
1987–1988	243.9	53.5	55.1	154.7	507.2
1988–1989	177.1	46.7	22.5	114.4	360.8
1989–1990	198.7	39.6	25.2	118.9	382.4
1991–1992	264.8	55.3	58.6	117.5	496.2
1992–1993	294.4	55.7	53.7	127.6	531.5
1993–1994	298.7	44.4	30.0	129.4	502.5
1998–1999	222.8	37.6	31.1	100.3	391.8
1999–2000	425.1	67.6	69.0	171.9	733.6

[a] Data from California Department of Fish and Game (1987, 1988, 1989, 1991, 1992, 1993, 1998, 1999).

habitats to be flooded in fall, but winters were dry with little or no lowland flooding. In SJV, habitat consisted of 257–315 km^2 of seasonally-flooded managed wetlands in 3 blocks (about 80% in the Grassland Ecological Area and 10% each in Mendota WA and the Tulare Lake basin; Fleskes 1999) and 31–47 km^2 of postharvest flooded fields, mostly in the Tulare Lake Basin. In SACV, 162–256 km^2 of managed wetlands and 537–847 km^2 of agricultural fields (mostly rice) flooded after harvest (Fleskes et al. 2005*a, b*), provided a relatively contiguous block of habitat. In DELTA, 95–128 km^2 of grain and other fields flooded after harvest and 13–26 km^2 of managed wetlands provided habitat (excludes 17 km^2 of riverine wetlands; Heitmeyer et al. 1989). Suisun Marsh provided 153 km^2 of managed marsh (excludes 70 km^2 of brackish wetlands; Heitmeyer et al. 1989). San Francisco Bay, to the west of the Central Valley, consisted of salt ponds, tidal and diked marsh, and open bay (USFWS 1979).

Nearly all duck clubs in the Grassland Ecological Area and most WAs and NWRs throughout central California (includes the Central Valley and San Francisco Bay) allowed hunting only 3 days each week. Kern NWR near the Tulare Lake basin allowed hunting 2 days each week, and many local duck-hunting clubs adopted those as hunting days. Many clubs outside SJV allowed hunting all days of the season.

METHODS

Field Procedures

We used field procedures during LATE similar to those used during EARLY to facilitate comparisons of survival among these periods. We captured all mallards during LATE with grain-baited swim-in traps in SACV, following procedures during EARLY (Heitmeyer 1989, Day et al. 1990). We captured pintails in SACV, SUISM, or SJV during LATE with rice-baited or unbaited rocket-nets (Schemnitz 1994) just as was done during EARLY (Miller et al. 1993, Fleskes 1999), except for 53 of the SACV pintails that Miller et al. (1995) captured with rice-baited swim-in traps (Table 4). We and the earlier researchers captured pintails and mallards during late August to mid-October before duck hunting season opened, except for a few mallards during EARLY captured during the mid-November to mid-December split between hunt1 and hunt2 (Heitmeyer 1989, Day et al. 1990). Capture locations were the same all years, except no pintails were captured at Delevan NWR, Graylodge WA, Butte Sink duck clubs (adjacent to Graylodge WA), or in the Tulare Lake Basin, and no mallards were captured at Sutter NWR or Butte Sink duck clubs during LATE (Table 4). We weighed ($\pm$5 g), measured (flat wing, culmen 1, total tarsus [Dzubin and Cooch 1992] $\pm$ 0.01 mm), aged (hatch-year [HY] or after-hatch-year [AHY]; Larson and Taber 1980, Duncan 1985, Carney 1992), and leg-banded captured ducks. We radio-tagged only AHY female pintails, and both AHY and HY female mallards, except in 1998 when we did not tag HY female mallards. We attached 20-g to 21-g pintail and 23-g to 26-g mallard (2.0–3.2% of body mass) radiotags with back-mounted harnesses (Dwyer 1972), except Fleskes (1999) tagged 34 pintails with 8-g to 9-g spear-suture transmitters in SJV in 1993 (radiotag type was not related to winter survival; Fleskes 2003). We released radiotagged ducks at the capture site $<$1 hour to 19 hours (most 3–8 hr) after capture with others from the same capture. Each radiotag had a unique signal, a mortality sensor, life expectancy $\geq$215 days, and an initial minimum range of 3.2 km ground-to-ground with a 150-db receiver and dual 4-element Yagi antennas mounted on the roof of a pickup truck. We imprinted radiotags with contact information and solicited information from hunters by posting project descriptions at hunting check stations and in statewide media. An Animal Care and Use Committee reviewed and approved our methods to ensure that they were in compliance with the Animal Welfare Act and United States Government Principles for the Utilization and Care of

Table 4. Date, location, and number of female northern pintails and mallards radiotagged and tracked during 1987–1994 (EARLY) and 1998–2000 (LATE)[a] in California's Central Valley, USA.

	EARLY			LATE		
Species–region	**Date**	***n***	**Location[b]**	**Date**	***n***	**Location**
Pintail–Sacramento Valley	23 Aug–7 Sep 1987	33	Sac NWR	27–31 Aug 1998	50	Sac NWR
		21	Delevan NWR	31 Aug–2 Sep 1999	50	Sac NWR
	21–30 Aug 1988	48	Sac NWR			
		12	Delevan NWR			
		3	Graylodge WA			
	22–30 Aug 1989	73	Sac NWR			
		3	Butte Sink Club			
Pintail–Suisun Marsh	29 Aug–23 Sep 1991	55	Suisun Marsh	12–15 Sep 1998	50	Suisun Marsh
	28 Aug–16 Sep 1992	61	Suisun Marsh	7–22 Sep 1999	50	Suisun Marsh
Pintail–San Joaquin Valley	29 Aug–6 Oct 1991	44	Grassland EA	4–22 Sep 1998	20	Grassland EA
		22	Mendota WA		30	Mendota WA
		12	Tulare Lake Basin	6 Sep–5 Oct 1999	33	Grassland EA
	31 Aug–5 Oct 1992	30	Grassland EA		22	Mendota WA
		17	Mendota WA			
		18	Tulare Lake Basin			
	28 Aug–25 Sep 1993	64	Grassland EA			
		47	Mendota WA			
		17	Tulare Lake Basin			
Mallard–Sacramento Valley	29 Sep–14 Oct 1988	9	Graylodge WA	30 Aug–15 Sep 1998	11	Graylodge WA
		22	Butte Sink Club		39	UBB WA
		14	Sutter NWR	28 Aug–13 Sep 1999	102	Graylodge WA
	16–25 Nov 1988	16	Butte Sink Club			
	7–16 Sep 1989	3	Graylodge WA			
		29	Butte Sink Club			
		7	UBB WA			
		11	Sutter NWR			
	25 Nov–16 Dec 1989	8	Butte Sink Club			
		20	Graylodge WA			

[a] After-hatch-yr, except 34 hatch-yr mallards in 1988, 49 in 1989, and 45 in 1999.
[b] Capture locations, including Sacramento (Sac) National Wildlife Refuge (NWR), Upper Butte Basin (UBB) Wildlife Area (WA), and Grassland Ecological Area (EA).

Vertebrate Animals Used in Testing, Research, and Training policies.

We distributed similar day- and night-tracking effort among regions during EARLY and LATE. We recorded status (location, alive or dead) of each duck 1–2 times per day during hunting seasons and usually at least every other day during nonhunting seasons from the date of the first capture until the end of March each year (approx. 215 d). We conducted aerial searches (Gilmer et al. 1981) of waterfowl habitat, urban, and rural areas for missing ducks weekly throughout central California during all studies. We censored (i.e., excluded data thereafter) ducks that left central California and any equipped with failing radiotags as evidenced by abnormal signals. We censored ducks that shed radiotags (mostly spear-suture; Fleskes 2003) on the date they shed their radiotags. We censored ducks that did not adjust to their radiotags, as evidenced by their failure to make feeding flights and being killed by predators 1–6 days after marking. We and the other researchers determined the timing and cause of death by site and carcass evidence and a review of the bird's movements (Fleskes 1999). We recorded deaths reported by hunters and other observers.

Data Analysis

We conducted known-fate modeling with Program MARK (White and Burnham 1999) to examine variation in pintail and mallard weekly survival rates. We used Akaike's Information Criterion values adjusted for small sample sizes (AIC_c; Akaike 1985, Burnham and Anderson 1998) to evaluate and compare statistical support for models that included planned combinations of factors of interest.

We first evaluated the importance of capture covariates that may have varied among study years and influenced winter survival (Fleskes et al. 2002*a*). These factors included body mass of the females at capture (standardized by age class for each species), age class (only for mallards; HY or AHY), capture season (only for mallards; prehunt or split), capture date (d before start of hunt1 [and hunt2 for mallards]), and capture site management (only for mallards; private duck club vs. NWRs or WAs). We also tested capture site within region (Sacramento NWR vs. Delevan NWR vs. other location for SACV pintails, Grasslands Ecological Area vs. Mendota WA vs. Tulare Lake Basin for SJV pintails, Sutter NWR vs. other [Upper Butte Basin WA, Gray Lodge WA, Butte Sink clubs] for mallards), separately by capture region (SACV, SUISM, or SJV) for pintails. We included season (prehunt, hunt1, split, hunt2, or posthunt for pintails, and as hunt or nonhunt for mallards) in this initial analysis because it was an important factor in other Central Valley survival studies (Fleskes et al. 2002*a*).

After our initial evaluation of the importance of capture covariates and season, we evaluated variability in survival among years, study periods, and winter regions, and characteristics of the Central Valley wintering environment that could explain temporal or regional variation in survival. To avoid overparameterization, we included capture covariates only if they improved model fit. However, because we did not distribute our radiotagged sample proportionate to pintail distribution in the Central Valley during our trapping period (Table 4), we included capture region in the pintail models so that we could calculate regional survival estimates. We compared support for models that included 1) study year; 2) study period (EARLY: 1987–1990 and 1991–1994 for pintails, 1988–1990 for mallards; LATE: 1998–2000 for both species); or 3) no temporal effect. For modeling the effect of wintering region (SACV, SUISM, DELTA, or SJV) for pintails, we treated pintails as censored when they left a region of interest and as captured when they entered a region of interest. We evaluated the importance of 1) area of flooded wetland and cropland habitat (HAB; Table 1); 2) early January abundance of each species (JPIN or JMAL; Table 2); and 3) number HDY (Table 3) in the Central Valley wintering region(s) where each radiotagged bird was located. Because these variables were closely correlated, we also defined a combined hunting pressure index (HPI). We calculated HPI by dividing HDY by the product of HAB and JPIN or JMAL because we theorized that the effect of hunting on the survival of an individual duck would increase as the number of hunters and hunt season duration increased, and decrease as abundance of the species and habitat in the region increased. Since HAB, JPIN (or JMAL), HDY, and HPI covaried with one another and with wintering region, we did not include >1 of these factors in any model. In addition, because we studied mallards during only 4 years and in only one wintering region, year models with HAB, JMAL, HDY, or HPI would be overparameterized and we did not test them. Also, we found HAB in the SACV and period highly correlated, so we did not test the period model with HAB for mallards. We used annual estimates of HAB, JPIN (or JMAL), HDY, and HPI in models that also included year and period averages for each in models that also included period. Not counting models to test capture covariates and season, we calculated and compared AIC_c for 18 pintail survival models and 10 mallard models to determine whether wintering region or temporal effects might be explained by JPIN (or JMAL), HAB, HDY, or HPI.

We used model averaging to estimate weekly mortality, winter survival, and effects of covariates, and included any of the 18 pintail or 10 mallard models that had >1% AIC_c weight (Burnham and Anderson 1992). We standardized rates to mean covariate values. We present estimates of weekly mortality (rather than weekly survival) because, although the models can estimate odds or probabilities, the parameters of the models only estimate effects on the odds. Also, since weekly probability of mortality $(1 - p)$ is near zero, the odds of mortality $([1 - p]/p)$, are almost equivalent, and therefore all effects on odds of mortality are approximately equal to effects on probability of mortality. We estimated change in weekly odds of mortality ($\bar{x} \pm$ SE) for important model factors directly in Program MARK (White and Burnham 1999) by using only models that included the factor and manipulating the design matrix when necessary and transforming beta values.

RESULTS

Causes, Location, and Timing of Mortalities

Of the 885 pintails and 291 mallards successfully radiotagged, 109 pintails and 65 mallards died in central California during the winter in which we radiotagged them. This excludes one pintail censored because of a failing radiotag before being reported shot and one censored when it left central California before being reported shot near Salton Sea. Hunting was the main cause of mortality for both pintails (79/109 = 72%) and mallards (59/65 = 91%); predators killed 17 pintails and 2 mallards (all but 4 during prehunt); disease killed 9 pintails (1 in prehunt, 3 in hunt2, and 5 during posthunt); 1 pintail and 1 mallard died after colliding with power lines; and 3 mallards and 3 pintails died of an undetermined cause. Most legal hunting mortality occurred during hunt2 for SACV pintails (9/10 = 90%; 2 were illegally shot during posthunt) and SUISM pintails (17/26 = 65%) but not SJV pintails (19/41 = 46%). For mallards, most (12/22 = 55%) hunting mortality occurred in hunt2 during EARLY but not during LATE (9/37 = 24%), mainly because 8 AHY and 6 HY mallards were shot during the very windy opening weekend of hunt1 in 1999. All SACV mallard and nearly all (21/23) SACV pintail mortality occurred in SACV, reflecting that few wintered outside SACV. In contrast, 34% (12/35) of SUISM and 27% (14/51) of SJV pintail mortalities occurred in SACV, reflecting that most moved to SACV during winter. Other SUISM pintail deaths occurred in SUISM (37%), DELTA (14%), SJV (9%), and San Francisco Bay (6%). Most SJV pintail deaths occurred in SJV (67%); 2 died in DELTA and 1 in SUISM.

Adult Female Pintail Survival

The highest-ranked pintail survival model included capture region, season, period, and winter region (Table 5). The analysis to evaluate the importance of capture covariates and season indicated that season greatly improved ($\Delta AIC_c = 60.84$) the model that had capture region but capture body mass ($\Delta AIC_c = 0.72$), capture date ($\Delta AIC_c = 2.00$), or capture site within region ($\Delta AIC_c \geq 1.94$) did not. Thus, in addition to capture region (to allow regional estimates) we included season in all models for analyzing temporal factors (yr vs. period vs. no temporal effect), wintering region, HAB, JPIN, HDY, and HPI. We tested an equal number (6) of models with period, year, and no temporal effect. The 6 models with period accounted for 98.9% of the weight (Table 5), providing strong evidence for a difference between EARLY and LATE survival rates. Models with year and no temporal effects accounted for only 0.9% and 0.1% of the weight, respectively. Models with winter region, JPIN, HAB, HPI, or HDY that also included period

Table 5. Number of parameters (K), Akaike's Information Criterion values adjusted for small sample size (AIC_c), ΔAIC_c, and AIC_c weights we used to rank models containing factors hypothesized to affect winter (late Aug–Mar) survival of adult female northern pintails in the Central Valley of California, USA, during an EARLY period (1987–1990, 1991–1994), when habitat changes due to the Central Valley Joint Venture and changing agricultural practices were occurring, and during a LATE period (1998–2000) after these changes were in place.

Model[a]	K	AIC_c	ΔAIC_c	AIC_c wt
Capreg + season + period + winreg	11	1,187.16	0.00	0.38
Capreg + season + period + JPIN	9	1,188.80	1.64	0.17
Capreg + season + period + HAB	9	1,189.28	2.13	0.13
Capreg + season + period + HPI	9	1,189.31	2.16	0.13
Capreg + season + period + HDY	9	1,189.65	2.50	0.11
Capreg + season + period	8	1,190.27	3.11	0.08
Capreg + season + yr + winreg	17	1,196.52	9.36	0.00
Capreg + season + yr + JPIN	15	1,198.17	11.01	0.00
Capreg + season + yr + HAB	15	1,198.56	11.40	0.00
Capreg + season + yr + HPI	15	1,198.74	11.58	0.00
Capreg + season + yr + HDY	15	1,198.89	11.73	0.00
Capreg + season + yr	14	1,199.39	12.23	0.00
Capreg + season + JPIN	8	1,200.85	13.70	0.00
Capreg + season + HAB	8	1,200.89	13.74	0.00
Capreg + season + HPI	8	1,201.83	14.68	0.00
Capreg + season + HDY	8	1,203.62	16.47	0.00
Capreg + season + winreg	10	1,203.93	16.77	0.00
Capreg + season	7	1,208.65	21.49	0.00

[a] Capture region (capreg) is the region (Sacramento Valley [SACV], Suisun Marsh [SUISM], San Joaquin Valley [SJV]) where the pintail was radiotagged in late Aug–early Oct; wintering region (winreg) is the region(s) (SACV, SUISM, SJV, Sacramento–San Joaquin River delta) where the pintail was later located; seasons (prehunt, hunt1, split, hunt2, posthunt) are based upon "balance of state" duck hunting regulations (D. Yparraguirre, California Department of Fish and Game [CDFG], unpublished data); study yr (yr) are 1987–1988, 1988–1989, 1989–1990, 1991–1992, 1992–1993, 1993–1994, 1998–1999, and 1999–2000; HAB is area of wetland and flooded cropland habitat in the winreg (Fleskes et al. 2005*b*); JPIN is early Jan abundance of pintails in the winreg (U.S. Fish and Wildlife Service 1988, 1989, 1990, 1992, 1993, 1994, 1999, 2000); HDY is the no. of hunter-days in the winreg (CDFG 1987, 1988, 1989, 1991, 1992, 1993, 1998, 1999); HPI is the hunting pressure index, calculated by dividing HDY by the product of JPIN and HAB.

ranked higher than the same models without period, indicating that there were period differences not accounted for by those factors. Conversely, adding winter region, JPIN, HAB, HPI, or HDY to the period model improved ranking, indicating that those factors were related to pintail survival. The model with winter region ranked higher than models with JPIN, HAB, HPI, or HDY, indicating that differences among winter regions other than those described by JPIN, HAB, HPI, or HDY also affected survival.

Winter survival during LATE was greater than during EARLY for pintails from all capture regions (Table 6). Averaging across all regions, odds of weekly mortality during EARLY were 149 ± 30% higher than during LATE. Weekly probability of mortality was much greater during hunting (hunt1 and hunt2) than during nonhunting (prehunt, split, and posthunt) seasons for pintails from all regions (Table 6). Averaged across all regions and years, odds of weekly mortality during hunt1 and hunt2 were 490 ± 127% and 1,001 ± 217% higher, respectively, and during prehunt and split were 68 ± 8% and 87 ± 6% lower, respectively, than during posthunt. Pintails radiotagged in SUISM or SJV had 61 ± 26% higher odds of weekly mortality than pintails radiotagged in SACV. Compared to in SACV, odds of weekly mortality were greater for pintails wintering in SJV (23 ± 15%) or SUISM (37 ± 17%) but similar for pintails wintering in DELTA (−8 ± 15%). HPI ranged from 0.003 to 0.208, and a 0.1-unit increase in HPI increased odds of weekly mortality 23 ± 15%. Additional pintails, 10 km^2 of flooded habitat, and HDY were each associated with an 18–21 ± 10% reduction in odds of weekly mortality.

Female Mallard Survival

The highest ranked mallard survival model included season, year, and age, but 1 model with period and 4 models without a temporal effect were within 2 AIC_c units (Table 7). The initial analysis indicated that season ($\Delta AIC_c = 49.96$) and age ($\Delta AIC_c = 4.29$) greatly improved the survival model, but capture mass ($\Delta AIC_c = 0.13$), capture season ($\Delta AIC_c = 1.01$), capture date ($\Delta AIC_c = 6.00$), capture site ($\Delta AIC_c = 1.20$), or capture site management ($\Delta AIC_c = 0.18$) did not. Thus, we included season and age in all models for analyzing temporal factors, HAB, JMAL, HDY, and HPI. The model with HPI ranked higher than models where HPI was replaced by HDY, JMAL, or HAB (Table 7). Similar to those of pintails, mallard mortality rates during hunting

Table 6. Estimated weekly mortality rate percentage (mort) by season and overall winter (late Aug–Mar) survival rate percentage (surv) for after-hatch-year female northern pintails by capture region and study period, 1987–2000.[a]

Capture region	Study period	Prehunt		Hunt1		Split		Hunt2		Posthunt		Winter	
		Mort	SE	Mort	SE	Mort	SE	Mort	SE	Mort	SE	Surv	SE
SACV	EARLY	0.21	0.07	0.89	0.26	0.13	0.08	1.21	0.34	0.23	0.10	87.6	3.0
	LATE	0.08	0.03	0.36	0.13	0.05	0.04	0.49	0.17	0.09	0.05	93.2	2.1
SUISM	EARLY	0.43	0.14	1.80	0.48	0.27	0.16	2.44	0.55	0.46	0.18	77.0	3.7
	LATE	0.17	0.06	0.73	0.22	0.11	0.07	1.00	0.26	0.19	0.08	86.6	3.2
SJV	EARLY	0.43	0.14	1.80	0.46	0.27	0.16	2.44	0.50	0.46	0.17	76.9	4.1
	LATE	0.17	0.07	0.73	0.23	0.11	0.07	1.00	0.26	0.19	0.08	86.6	3.1

[a] Capture region (SACV: Sacramento Valley, SUISM: Suisun Marsh, SJV: San Joaquin Valley) is where the pintail was radiotagged in late Aug–early Oct; seasons are based upon "balance of state" duck hunting regulations (D. Yparraguirre, California Department of Fish and Game, unpublished data); study period yr during EARLY were 1987–1990 for SACV, 1991–1993 for SUISM, and 1991–1994 for SJV, and during LATE were 1998–2000. Estimates are based on covariates standardized to their mean values (Jan pintails: 360,300; flooded habitat: 527 km^2; hunter-days: 173,200; and wintering 46% in SACV, 21% in SJV, 18% in Sacramento–San Joaquin River delta, and 14% in SUISM).

Table 7. Number of parameters (*K*), Akaike Information Criterion (AIC_c) values adjusted for small sample size, ΔAIC_c, and AIC_c weights used to rank models containing factors hypothesized to affect winter (late Aug–Mar) survival of female mallards radiotagged in Sacramento Valley, California, USA, during an EARLY period (1988–1990) when habitat changes due to the Central Valley Joint Venture and changing agricultural practices were occurring, and during a LATE period (1998–2000) after these changes were in place.[a]

Model[a]	*K*	AIC_c	ΔAIC_c	AIC_c wt
Season + age + yr	6	602.49	0	0.219
Season + age	3	603.25	0.76	0.150
Season + age + HPI	4	603.52	1.03	0.131
Season + age + period + HDY	5	604.02	1.53	0.102
Season + age + HDY	4	604.34	1.85	0.087
Season + age + JMAL	4	604.43	1.94	0.083
Season + age + period + JMAL	5	604.76	2.27	0.070
Season + age + period	4	605.25	2.76	0.055
Season + age + HAB	4	605.25	2.76	0.055
Season + age + period + HPI	5	605.49	3.01	0.049

[a] Seasons (hunting or nonhunting) are based upon "balance of state" duck hunting regulations (D. Yparraguirre, California Department of Fish and Game [CDFG], unpublished data); study yr (yr) are 1988–1989, 1989–1990, 1998–1999, and 1999–2000; HAB is area of wetland and flooded cropland habitat (Fleskes et al. 2005*b*); JMAL is early Jan abundance of mallards (U.S. Fish and Wildlife Service 1988, 1989, 1990, 1992, 1993, 1994, 1999, 2000); HDY is the no. of hunter-days (CDFG 1987, 1988, 1989, 1991, 1992, 1993, 1998, 1999); HPI is the hunting pressure index, calculated by dividing HDY by the product of JMAL and HAB.

season were much higher than during nonhunting seasons (Table 8), and the odds of weekly mortality during hunting season were 95 ± 1% higher than during nonhunting seasons. The odds of weekly mortality for HY were 53 ± 7% higher than for AHY female mallards. Hunting pressure index ranged from 0.009 to 0.013, and a 0.1-unit increase in HPI was associated with a 22 ± 18% increase in weekly mortality. Additional mallards in the region were associated with a 25 ± 20% decrease in weekly mortality, but additional flooded habitat was associated with no significant effect on survival (0 ± 1%). Additional hunter days were associated with a 31 ± 30% increase in weekly mortality.

DISCUSSION

Factors Related to Survival

Hunting was the main source of mortality for both pintails and mallards. Thus, variation in factors that affected hunting mortality mostly was responsible for the temporal and regional variation in winter survival that we observed. We found that increased HPI was associated with reduced survival for both pintails and mallards. Migoya and Baldassarre (1995) reported high winter survival of pintails in Mexico and theorized that the large habitat area and few hunters there resulted in low hunter pressure relative to California and Louisiana, USA. Our data indicate that hunting pressure also varied within California, with hunting mortality lower in SACV than in other regions. Lower hunting mortality for pintails in SACV compared to that in other regions is consistent with Rienecker (1987*b*), who reported that direct recovery rates were lower for female pintails banded during 1949–1963 in SACV than for those

Table 8. Estimated weekly mortality rate percentage (mort) during nonhunting and hunting seasons and overall winter (late Aug–Mar) survival rate percentage (surv) for after-hatch-year (AHY) and hatch-year (HY) female mallards radiotagged in Sacramento Valley, California, USA, during 1988–1990 and 1998–2000.[a]

		Nonhunting		Hunting		Winter	
Age	Yr	Mort	SE	Mort	SE	Surv	SE
AHY	1988–1989	0.14	0.09	2.45	1.01	80.1	7.2
AHY	1989–1990	0.12	0.07	2.08	0.77	82.8	5.6
AHY	1998–1999	0.10	0.06	1.89	0.67	74.4	7.7
AHY	1999–2000	0.12	0.07	2.22	0.66	70.6	7.2
HY	1988–1989	0.28	0.16	4.59	1.51	63.5	8.8
HY	1989–1990	0.24	0.14	4.29	1.29	67.6	8.0
HY	1999–2000	0.26	0.14	4.54	1.13	48.7	9.1

[a] Seasons are based upon "balance of state" duck hunting regulations (D. Yparraguirre, California Department of Fish and Game, unpublished data); estimates are based on covariates standardized to their mean values (Jan mallards: 265,200; flooded habitat: 911 km^2; hunter-days: 259,300).

banded during 1950–1961 in the northern SJV. Although correlation of individual factors that composed HPI complicated our ability to model each factor's effect on pintail or mallard survival, our analysis does provide some insight into these relationships.

Habitat.—Increased area of flooded habitat was associated with increased pintail survival. For example, SACV had more flooded habitat than other Central Valley regions, and pintails wintering there had comparatively higher survival. Pintail survival and HAB both increased from EARLY to LATE. Survival increased more between periods for pintails radiotagged in SJV (+12.6%) or SUISM (+12.5%) than in SACV (+6.4%; Table 6), whereas HAB increased more in SACV (+58%) than in SJV (+14%) or SUISM (0%; Table 1). However, SJV and SUISM pintails moved to SACV earlier in winter during LATE than during EARLY (Fleskes et al. 2002*b*, 2005*a*), and therefore the increase in SACV habitat between periods had a greater effect on their survival than for pintails radiotagged in SACV. Also, SACV pintail survival already was high during EARLY with little margin to increase. We did not detect a significant relationship between HAB and survival of SACV mallards. Within SACV, where habitat was already abundant during EARLY compared to other regions, change in other factors (e.g., HDY, JMAL) had more of an effect on mallard survival than the large increase in area of flooded habitat.

Pintail survival was related to HAB, but change in extent of this factor alone does not completely account for the period and regional differences in pintail survival that we observed. Data were not adequate to model landscape characteristics other than HAB that could have affected hunting mortality. We speculate that regional and period differences in area and management of sanctuaries, types of feeding habitats (e.g., rice, wetland), and juxtaposition of sanctuaries and feeding habitats influenced survival. For instance, only about 6% of wetland habitat on WAs and NWRs in the northern SJV was closed to waterfowl hunting compared to 25% in SACV (Central Valley Habitat Joint

Table 9. Winter survival (%) of after-hatch-year (AHY) and hatch-year (HY) female mallards in California, USA, and other North American wintering areas, 1968–2000.

Region	Study yr	Age	Winter survival	SE
CA-Sacramento Valley[a]	1988–1989	AHY	80	7
CA-Sacramento Valley[a]	1989–1990	AHY	83	6
CA-Sacramento Valley[a]	1998–1999	AHY	74	8
CA-Sacramento Valley[a]	1999–2000	AHY	71	7
MS and AR[b]	1980–1985	AHY	84	
MN[c]	1968–1974	AHY	88	
CA-Sacramento Valley[a]	1988–1989	HY	63	9
CA-Sacramento Valley[a]	1989–1990	HY	68	8
CA-Sacramento Valley[a]	1999–2000	HY	49	9
MS and AR[b]	1980–1985	HY	70	
MN[c]	1968–1974	HY	64	
Mid-continent North America[d]	1981–1985	Both	96	10
TX[e]	1986–1988	Both	78	4
AR[f]	1988–1989	Both	99	1

[a] This radiotelemetry study.
[b] Reinecke et al. (1987); 180 AHY or 43 HY radiotagged F.
[c] Kirby and Cowardin (1986); fall–winter estimate calculated as quotient of banding-derived annual survival divided by spring–summer estimate from 109 radiotagged F.
[d] Blohm et al. (1987); fall–winter estimate from 535 recoveries of 11,595 banded F.
[e] Bergan and Smith (1993); 76 AHY and 77 HY radiotagged F; no age effect found.
[f] Dugger et al. (1994); posthunt estimate from 49 AHY and 43 HY radiotagged F.

Venture Technical Committee 1996). In addition, unlike during EARLY, some rice fields in SACV during LATE were flooded mainly to promote straw decomposition (Elphick 1998) and not all were hunted regularly, providing additional sanctuary (Fleskes et al. 2005*b*). In contrast, habitat in the northern SJV and SUISM consisted almost exclusively of seasonal wetlands managed specifically for waterfowl and hunting (Casazza 1995, Fleskes 1999) and hunting was a primary purpose for most fields flooded during winter in DELTA (Casazza 1995).

Local waterfowl abundance.—We found that survival of mallards and pintails was directly related to their abundance in the region. We expected this would occur because hunting was the main source of mortality during winter, and harvest regulations did not track population change. For instance, the daily bag limit for female pintails remained at 1 during both study periods even though pintail abundance increased 45% in the Central Valley of California (Table 2). Thus, with a constant daily bag limit of 1, and assuming all else constant, the odds of a female pintail being shot on any day would be inversely related to its local abundance. We suspect that abundance of other waterfowl species also may have affected hunting pressure. For instance, harvest pressure on pintails may be greater in SJV than in SACV because mallards and other species preferred by hunters are less abundant in SJV (USFWS 2000).

Hunter-days.—Mallard survival was inversely related to HDY, as expected, but pintail survival was not. The unexpected direct relation between HDY and pintail survival was probably an artifact of managers increasing hunting season duration (resulting in increased HDY) as continental waterfowl populations increased. Although we did not include bag limit in our measure of hunting pressure, bag limits also likely affected survival. We see this effect by comparing SACV pintails and mallards. Both wintered almost exclusively in SACV and encountered the same increase in HDY, HAB, and hunt season duration between EARLY and LATE. However, the female daily bag limit for mallards doubled from 1 during EARLY to 2 during LATE but for pintails remained 1 both periods. Thus, despite a 55% increase in JMAL versus only a 26% increase in JPIN across periods in SACV (Table 2), survival increased for SACV female pintails (Table 6) but not for mallards (Table 8). A bag limit of 2 female mallards multiplied the effect of high harvest vulnerability due to a very windy 1999 opening weekend, and resulted in the lowest female mallard survival reported for any North American wintering area (Table 9).

Nonhunting Mortality

Nonhunting mortality had a small effect on winter survival compared to hunting. Most predation occurred during prehunt probably because duck abundance increased rapidly on limited wetlands (Miller et al. 1995). Based upon the late-winter timing and confirmed cases, avian cholera was mainly responsible for disease losses during our study. Avian cholera losses during our study (0.9% of the F pintails but none of the F mallards) were within the range (0.2–2.0%) reported for the wintering duck population in California calculated by extrapolating numbers of recovered carcasses (see Botzler 1991) but less than the 4.5% loss rate estimated for midcontinent mallards (Samuel 1992).

Are Rates That We Measured Representative of Pintails and Mallards in California?

We radiotagged pintails in their 3 main California wintering regions (USFWS 2000) but mallards only in SACV. As a result, our regional estimates encompass the range of survival rates for most AHY female pintails that winter in California, but our estimates for female mallards should be considered representative only of SACV.

We did not distribute our radiotagged sample of female pintails proportionate to regional abundance of pintails in the Central Valley during our trapping period. Therefore, to estimate an average winter survival rate for California pintails, our regional estimates should be weighted by abundance of pintails in each region. In addition, although we radiotagged most of our sample during prehunt when pintail and mallard abundance was rapidly increasing, their abundance did not peak in the Central Valley until December (Fleskes et al. 2005*b*). Later arrivals could have different survival or be affected differently by habitat changes among study periods. Most data indicate that the radiotagged sample provided relatively unbiased winter survival estimates (Fleskes et al. 2002*a*, Fleskes 2003). Further, the regional differences in pintail survival we observed are consistent with banding data (Rienecker 1987*b*). Regardless, we used similar field techniques all

Table 10. Winter survival (%) of radiotagged after-hatch-year (AHY) female northern pintails and average duration each winter that they were radiotracked in California, USA, and other North American wintering areas, 1987–2004.

Region where radiotagged	Study yr	Duration (d)	Winter survival	SE
CA-Sacramento Valley[a]	1987–1990	215	88	3
CA-Sacramento Valley[a]	1998–2000	215	93	2
CA-SJV and SUISM[a]	1991–1994	215	77	4
CA-SJV and SUISM[a]	1998–2000	215	87	3
Mexico-Sinaloa[b]	1989–1992	105	91	2
LA-southwestern[c]	1990–1993	147	71	4
NM-Rio Grande[d]	2001–2003	120	67	10
TX-Playa Lakes[e]	2002–2003	130	92	4
TX-Playa Lakes[e]	2003–2004	140	69	6

[a] Estimated in this study (SJV: San Joaquin Valley, SUISM: Suisun Marsh).
[b] Migoya and Baldassarre (1995); 88 AHY and 75 hatch-yr; no age-class effect found.
[c] Cox et al. (1998); 233 AHY.
[d] Lee (2003); 32 F; no. of each age class not reported and age effect not tested.
[e] Moon and Haukos (2006); 197 AHY and 123 hatch-yr; no age-class effect found.

study years, so any bias in estimates would likely be consistent and would not impair our comparison of survival among study years or periods.

Survival in California Compared to Other Wintering Areas

Winter survival of adult female pintails in California was within the reported range, and survival of SACV pintails during LATE exceeded any reported for other wintering areas in North America, even though our study duration was 68–110 days longer than in the other areas (Table 10). Our estimates for survival of female pintails in California during LATE were 2–3 times greater than preliminary estimates for pintails wintering in southern Texas, USA, during 2002–2004 (B. Ballard, Caesar Kleberg Wildlife Research Institute, unpublished data). Winter survival rates of SACV mallards were also within the reported range (Table 9). However, with increased bag limits and season duration, mallard survival during LATE was lower than in most other wintering areas. During 1948–1982, annual survival rates of adult (56%) and immature (46%) female mallards banded in central California were similar to continental estimates during those years (Rienecker 1990). This suggests that winter survival of mallards in California has either declined more or failed to increase as much as elsewhere in North America during 1988–2000.

MANAGEMENT IMPLICATIONS

Managers can manipulate winter survival of female pintails and mallards in the Central Valley by adjusting harvest regulations because most mortality is from hunting. However, abundant quality winter habitat is crucial to maintain low rates of natural mortality, and most waterfowl habitat in California is privately owned and managed for hunting (Gilmer et al. 1982). Thus, we recommend that when setting hunting regulations, managers weigh the uncertain benefits to waterfowl populations of increased winter survival (Nichols et al. 1995) against benefits of allowing sustainable harvest at a level that helps maintain strong incentive for management of Central Valley waterfowl habitats, including the large portion that is privately owned.

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