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Distribution and derivation of dabbling duck harvests in the Pacific Flyway

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Hunters in the Pacific Flyway harvest a wide diversity of dabbling ducks, and better knowledge of the origins of these birds could assist in both harvest and habitat management. We used abundance, banding, and harvest data from throughout the Pacific Flyway and other important source areas in the Central Flyway to estimate the distribution and derivation of Pacific Flyway dabbling duck harvests during 1966–2013. Although most of the combined Pacific Flyway dabbling duck harvest was derived from Alaskan and Canadian sources, each Pacific Flyway state relied extensively on within-state production for at least some species, especially mallards (*Anas platyrhynchos*), gadwalls (*Mareca strepera*), cinnamon teal (*Spatula cyanoptera*), and wood ducks (*Aix sponsa*). Harvest from California was especially diverse, including large proportions of ducks produced in California in addition to migrants from throughout the Pacific and Central Flyways. Although the Pacific Flyway has long been recognized as a critical wintering area for dabbling ducks, our analyses indicate it is also an important production area for several species. Sustaining future waterfowl harvests will require continued recognition of the diverse production origins of waterfowl that winter in the Pacific Flyway.

Key words: band recoveries, California, dabbling ducks, derivation, distribution, harvest, Pacific Flyway, waterfowl

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Management of migratory waterfowl benefits from reliable knowledge of the connections between production (i.e., breeding) and harvest areas (Osnas et al. 2014). Distribution of harvest describes where birds from a specific production area are harvested, and given extended hunting seasons, such harvest can occur on breeding, migration, or wintering areas. Distribution of harvest can be estimated based on the relative proportion of band recoveries from a given production area, assuming reporting rates are equal among potential harvest areas (Henny and Burnham 1976). Derivation of harvest describes the production origins of birds harvested by hunters in a specific region, and in addition to band recovery data, requires abundance estimates from each production area for estimating relative banding effort (Munro and Kimball 1982). Methods for estimating harvest distribution and derivation were first developed by Geis et al. (1971) using data from American black ducks (*Anas rubripes*). Munro and Kimball (1982) further refined these methods, using population surveys, band recoveries, and harvest information to describe patterns of harvest distribution and derivation for North American mallards (*Anas platyrhynchos*) during 1961−1975. Their work was subsequently used to help describe boundaries for Eastern, Mid-continent, and Western mallard populations and aided in the development of adaptive harvest management (AHM) protocols (U.S. Fish and Wildlife Service 1999). Klimstra and Padding (2012) used derivation of harvest information to improve harvest management of four populations of Canada geese (*Branta canadensis*) wintering in the Atlantic Flyway. Their analysis showed that early harvest was comprised almost entirely of geese from an overabundant resident population, thus enabling development of special early seasons to exploit resident geese with minimal risk to less abundant migratory populations (Klimstra and Padding 2012). More recently, Szymanski and Dubovsky (2013) described connectivity between production and harvest areas for blue-winged teal (*Spatula discors*). Their analysis further demonstrated the effectiveness of the Conservation Reserve Program at improving blue-winged teal production throughout the Dakotas. Hence, analyses of waterfowl harvest distribution and derivation have helped identify important regions for both harvest and habitat management. From 2008−2016, AHM protocols for mallards in the Pacific Flyway relied on abundance estimates from California, Oregon, and Alaska. Abundance estimates from Washington and British Columbia were included beginning with the 2017 hunting season (U.S. Fish and Wildlife Service 2016), but breeding populations from Idaho, Nevada, and Utah are still excluded, as are populations from production areas located in the Mid-continent, especially Alberta (Alisauskas et al. 2014). Since 2010, a separate AHM protocol has guided bag limits for northern pintails (*Anas acuta*), but harvest strategies for most other dabbling ducks in the Pacific Flyway follow recommendations arising from the AHM western mallard population model (U.S. Fish and Wildlife Service 2016). It is therefore important to understand how harvest distribution and derivation for other important duck species compare to those of mallards. Our objectives were to describe the distribution and derivation of harvest for the nine most commonly harvested dabbling ducks within the Pacific Flyway: mallards, northern pintails, green-winged teal (*Anas crecca*), American wigeons (*Mareca americana*), gadwalls (*M. strepera*), northern shovelers (*Spatula clypeata*), cinnamon teal (*S. cyanoptera*), blue-winged teal, and wood ducks (*Aix sponsa*; we treat *Aix* as a dabbling duck for our analysis, but acknowledge that their taxonomic affinity remains uncertain).

Materials And Methods

Study area—North American waterfowl flyways are both ecological and administrative constructs (U.S. Fish and Wildlife Service 2015). Ecologically, the Pacific Flyway includes portions of North America that support waterfowl populations that winter primarily west of the Continental Divide. Administratively, the Pacific Flyway includes Alaska, Washington, Oregon, California, Idaho, Nevada, Utah, and Arizona, and western portions of Montana, Wyoming, Colorado, and New Mexico (Figure 1). Although they do not vote on U.S. regulation-setting decisions, British Columbia and Yukon Territory are also members of the Pacific Flyway, as are Baja California, Baja California Sur, Sonora, and Sinaloa, Mexico. For our analyses of harvest distribution and derivation, we included British Columbia and all U.S. states located wholly within the Pacific Flyway except Arizona, which had insufficient band recoveries for analysis.

Previous studies of harvest derivation (e.g., Munro and Kimball 1982) used banding reference areas (Anderson and Henny 1972) to delineate breeding populations. However, population surveys, banding data, and harvest data are typically organized by geopolitical boundaries, and states and provinces manage much of their own waterfowl habitat and set their own hunting regulations (subject to federal frameworks), so we used states and provinces as both source and harvest areas for our analyses (see also Szymanski and Dubovsky 2013). Because banding data were particularly sparse in northern Canada, we combined

FIGURE 1.—Map of North America illustrating the four waterfowl flyways.

Yukon and Northwest Territories (hereafter Yukon/NWT) and treated aggregated data as if they were from the Central Flyway (~90% of enumerated waterfowl were from NWT; Appendix 1). We also analyzed non-flyway sources of harvest from Alberta, Saskatchewan and Manitoba (pooled together), and Montana, North and South Dakota (pooled as Prairie U.S.). We initially summarized data from Colorado and Wyoming, but found that they contributed only 2-3% of the annual gadwall and mallard harvest for Utah and trace amounts (<0.2%) for other species and jurisdictions, so we excluded them from further consideration. Although we included mid-continent sources in our analysis, our estimates of harvest distribution were based solely on Pacific Flyway recoveries (e.g., we excluded ducks banded in Alaska that were harvested in the Central, Mississippi, and Atlantic Flyways).

Breeding population estimates—We estimated annual abundance (Nt) for each species (s) and production area (i) using data from three existing surveys: 1) the federal Waterfowl Breeding Population and Habitat Survey (WBPHS, U.S. Fish and Wildlife Service 2015); 2) state waterfowl surveys (Olson 2014); and 3) the Breeding Bird Survey (BBS; Sauer et al. 2011). The WBPHS primarily covers source areas outside the Pacific Flyway, including Prairie U.S., Prairie Canada, and Northwest Territory, but also includes portions of Yukon Territory and Alaska. State waterfowl surveys have been conducted since 1959 in Nevada, 1979 in Washington, 1990 in Utah, 1992 in California, 1994 in Oregon, and 2006 in British Columbia (Olson 2014, U.S. Fish and Wildlife Service 2015). The Breeding Bird Survey began coverage in western North America in 1968 (Sauer et al. 2011); however, coverage in northern regions of Canada and Alaska was limited, especially in early years. For Breeding Bird Survey data, we used state or province-level annual summaries of mean ducks per BBS route. Given 50 survey stops of 0.4 km (0.25 mile) radius, a single BBS route covers 25.1 km^2, and we extrapolated average route-specific BBS estimates to the entire landmass of each state or province (Zimmerman et al. 2015).

For states or provinces with two concurrent surveys, we paired data from BBS and WBPHS surveys (AK, YK, NT, AB, SK, MB, MT, ND, and SD) or BBS and state-specific surveys (WA, OR, CA, NV, and UT) and used Bayesian state-space models (Kéry and Schaub 2012) run in reverse time (2013-1966) to estimate joint population trajectories for each data set. We modeled a common growth rate (r_{sit}) for each population (e.g., $\log[N_{si(t-1)}] = \log[N_{sit}] + r_{sit}$), where r_{sit} was drawn from a normal distribution with vague priors (μ_r=0, σ_r^2=1000). Because log[0] is undefined, we assigned 0.5 ducks to one survey route during survey years when no ducks were detected during BBS surveys, and we assumed that BPOP surveys had counted one half of the minimum ducks observed during years with non-zero counts. We modeled annual observation error in each data set using log-transformed estimates of survey precision for WBPHS data (σ_{WBPHS}), but for BBS and state surveys we treated observation error as an unknown parameter with a vague prior distribution ($\sigma_{\log(N)}$ ~Uniform(0-3)) and for BBS data we further assumed that survey precision ($\sigma^{-2}_{\log BBS}$) was correlated with the number of BBS routes conducted each year. During periods when both surveys were operating, population trajectories were driven primarily by data from dedicated waterfowl surveys, but our joint modeling approach allowed us to estimate population sizes during earlier time periods when only BBS data were available (e.g., California: 1968−1991).

In states or provinces with both BPOP surveys and BBS routes, mean long-term estimates from the two surveys were positively correlated (r^2=0.67), and this correlation was stronger when we excluded BPOP surveys with fewer than 5,000 birds (r^2=0.77, Figure 2). However, BPOP surveys detected 7.8 times more ducks than did BBS surveys, averaged over all species and survey areas (Appendix 2). Species with widespread breeding populations in the southern Pacific Flyway (i.e., mallards, gadwalls, cinnamon teal, and wood ducks) had lower adjustment factors (3.6 BPOP:BBS) than did species with primarily boreal or mid-continent breeding distributions (i.e., pintails, wigeons, green-winged teal, northern shovelers, and blue-winged teal; 10.2 BPOP:BBS). We therefore used a 3.6× adjustment factor for BBS estimates from Pacific Flyway jurisdictions that only had BBS data (Idaho), or had insufficient BPOP data for joint modeling (British Columbia). Although Nevada and Utah both have dedicated BPOP surveys, BPOP estimates were consistently smaller than unadjusted BBS indices (Appendix 2). We therefore used adjusted BBS population estimates for both Nevada and Utah. Harvest derivation uses population estimates as regional weighting factors (Munro and Kimball 1982, Szymanski and Dubovsky 2013) and it is not critical that population estimates are unbiased so long as they function as constant proportion indices of spatiotemporal variation.

Banding and recovery data—We compiled preseason banding data from just over 3.4 million normal, wild-caught dabbling ducks banded in the Pacific Flyway and neighboring jurisdictions during 1966−2013 (Appendix 3). We included ducks banded as locals (i.e., flightless young of the year) or hatch years (flight-capable young of the year) in a combined juvenile category, but excluded birds of unknown age or sex at banding. We included birds marked with a single federal band, including those captured by spotlighting, but excluded birds that were marked with auxiliary markers (e.g., nasal tags, patagial tags)

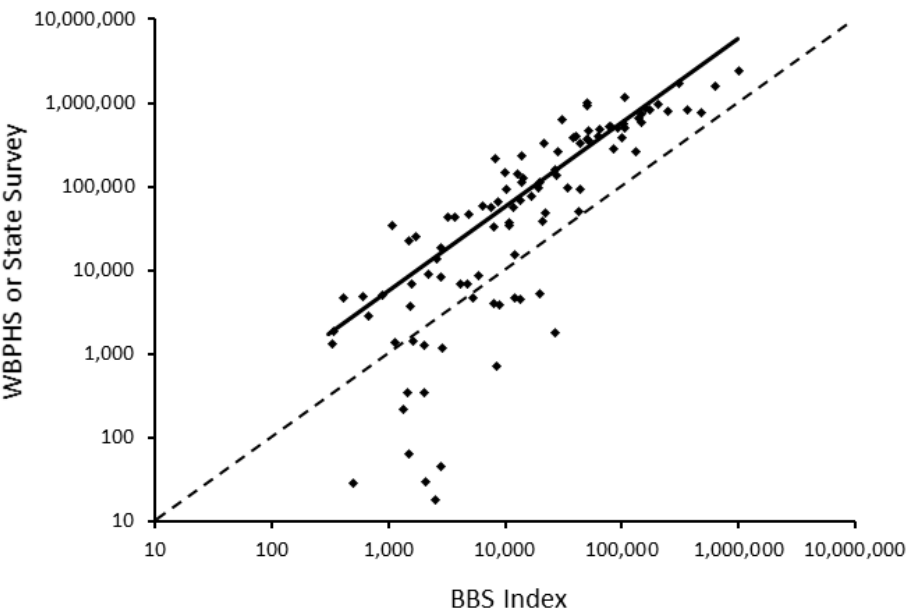

FIGURE 2.—Relationship between federal (WBPHS) or state waterfowl surveys and estimates based on the Breeding Bird Survey (BBS). Each data point represents a pair of estimates from a single state, province, or territory for a single species of dabbling duck (mallard, northern pintail, American green-winged teal, American wigeon, gadwall, northern shoveler, blue-winged teal, cinnamon teal, or wood duck). The correlation was 0.82 over all data and 0.88 for survey estimates >5,000. The dashed line indicates parity between estimate pairs, whereas the solid line represents the observed relationship where federal or state surveys observed 5.8-fold more ducks on average than the BBS survey.

because auxiliary-marked birds often have higher reporting rates (Arnold et al. 2016). Banding location was assumed to represent breeding location, but ducks banded in early fall can include migrants from other areas (Szymanski and Dubovsky 2013). Consequently, we used two different banding windows to account for variation in fall migration patterns and help eliminate early migrants from the data. For species known to migrate early (e.g., pintails, shovelers, blue-winged and cinnamon teal) we used bandings from 1 June to 31 August. For later migrants, including mallards, gadwalls, wigeons, and wood ducks, we extended the preseason banding window to 15 September to take advantage of the large number of birds that were banded during early September.

For each species (s), cohort (c; adult male, adult female, juvenile male, juvenile female), year (t), and banding region (i), we summarized total preseason banding effort (B_{scti}) and we then used direct band recoveries (R′=73,972, Appendix 3), defined as birds shot between 1 September and 31 January during the first fall or winter after banding, to estimate source-specific direct recovery rates from each harvest region (j):

$$\hat{\mathrm{f}}'_{\mathrm{sctij}} = \mathrm{R}'_{\mathrm{sctij}} / \mathrm{B}_{\mathrm{scti}}$$

This represents a source- and destination-specific index of annual harvest rate for each species, but because annual data were too sparse for analysis, we aggregated bandings and recoveries over the entire time period (1966−2013). We excluded species with 25 or fewer recoveries from state-specific analyses, but we included these data in regional summaries for the entire Pacific Flyway. For mallards, pintails, and gadwalls, which had more recovery data, we also estimated recovery rates separately for the first (1966−1989) and second halves of our study (1990−2013). Reporting rates are currently available only for mallards and eastern populations of wood ducks (Boomer et al. 2013, Garrettson et al. 2014); however, reporting rates are treated as constants in calculations of harvest derivation, so we omitted reporting rate adjustments from our analyses.

Harvest derivation resembles a Horvitz-Thompson estimator (Horvitz and Thompson 1952), except the number of birds banded from each production region (B_{scti}) is replaced by the estimated total population size for the source region ($\hat{N}_{scti}$) to account for unbanded birds in the harvest. For example, California's (CA) proportional harvest of adult male (AM) northern pintails (NOPI) from Alaska (AK) during 1966-2013 is estimated as:

$$= (\hat{N}_{sct,AK} * \hat{f}_{sct,AK,CA}) / \sum_{i=1}^{I} (\hat{N}_{scti} * \hat{f}_{scti,CA})$$

where the subscript sct = NOPI,AM,1966−2013 and 1 to I indicates all potential source areas contributing to California's pintail harvest (including Alaska).

Harvest data—Harvest estimates for the United States were obtained from the U.S. Harvest Information Program (Raftovich and Wilkins 2013). Harvest in British Columbia was obtained from the Canadian National Harvest website (Gendron and Smith 2015). Total harvest was partitioned into appropriate age and sex cohorts based on data from the Parts Collection Survey (Raftovich and Wilkins 2013). Parts that were incompletely identified to age or sex were assigned to cohorts using observed ratios from identified parts (Szymanski and Dubovsky 2013). The Parts Collection Survey cannot differentiate cinnamon teal from blue-winged teal (Carney 1992), but Szymanski and Dubovsky (2013) found that <1% of banded blue-winged teal from the mid-continent area were harvested in the Pacific Flyway. For our analyses, we combined data from both species and interpreted species composition based on production origins; teal derived from Prairie Canada or Prairie U.S. were presumed to be primarily blue-winged teal, whereas teal derived from California or the Great Basin were presumed to be primarily cinnamon teal (Appendix 3). We used harvest estimates to: weight derivation among cohorts (i.e., adult and juvenile males and females), calculate species-specific estimates of harvest derivation, weight estimates across species, calculate derivation of the entire dabbling duck harvest for each particular harvest jurisdiction, and weight estimates across all harvest jurisdictions to estimate derivation of the entire Pacific Flyway dabbling duck harvest (Munro and Kimball 1982).

Assumptions—Derivation of harvest analysis assumes that population surveys are proportional to population size at the time of banding (Munro and Kimball 1982). This further presumes that: 1) breeding birds and fledged offspring do not move among survey units prior to banding; and 2) age and sex ratios are equal among survey units; however, this latter assumption is less important given that we do not report age- and sex-specific variation in harvest derivation. Additionally, the use of banding and harvest data to evaluate these assumptions requires that: 3) banded samples adequately represent each breeding population; and 4) harvest samples are large enough to provide sufficient recoveries from all important breeding populations (Munro and Kimball 1982). We recognize that each of these assumptions is violated to some extent (Munro and Kimball 1982), and we consider these assumptions in greater detail in the Discussion.

Results

Distribution of Harvest—Mallards were the most widely distributed and harvested dabbling duck in the Pacific Flyway. Aside from Alaska and British Columbia, more than 60% of the mallards harvested from each Pacific Flyway jurisdiction were harvested within the same state where they were banded (Table 1). Mallards from Alaska and British Columbia were harvested primarily in the northern portion of the Pacific Flyway, especially Washington. Substantial portions of mallards banded in Oregon and Nevada were harvested in California, and many Idaho mallards were harvested in Washington (Table 1). Similar patterns occurred for gadwalls and wood ducks (Tables 2 and 3), except that greater proportions of both species were harvested by neighboring states (especially by hunters in California). For cinnamon teal, the only Pacific Flyway production area with >100 recoveries was California, and 99% of the harvest of California-produced birds occurred in California.

Table 1.—Percent distribution of mallard harvests from major Pacific Flyway source areas (columns) among major harvest jurisdictions (rows), 1966-2013. Harvest of local breeding populations is indicated along the main diagonal (values in bold). Trace amounts (< 0.005) were omitted to enhance readability.

	Pacific Flyway Source Areas:							
Harvested in:	**AK**	**BC**	**WA**	**OR**	**CA**	**ID**	**NV**	**UT**
Alaska	**47**							
B. Columbia	11	**26**	2			1		
Washington	27	39	**80**	7		17		
Oregon	12	16	12	**62**	3	8		
California	2	10	5	28	**96**	7	23	2
Idaho	1	10	1	2		**62**	1	5
Nevada							**75**	1
Utah						4	1	**91**

TABLE 2.—Percent distribution of gadwall harvests from Pacific Flyway source areas (columns) among major harvest jurisdictions (rows), 1966-2013. Only source areas with >100 recoveries and harvest areas with > 0.5% proportional harvest are included.

	Pacific Flyway Source Areas:				
Harvested in:	**WA**	**OR**	**CA**	**NV**	**UT**
Washington	**69**	3	1		
Oregon	5	**31**	17	1	1
California	26	58	**81**	49	10
Idaho		3			2
Nevada		3	1	**48**	1
Utah		2		2	**86**

TABLE 3.—Percent distribution of wood duck harvests from Pacific Flyway source areas (columns) among major harvest jurisdictions (rows), 1966-2013. Only source areas with >100 banding recoveries and harvest areas with > 0.5% proportional harvest are included.

	Pacific Flyway Source Areas				
	WA	**OR**	**CA**	**ID**	**NV**
Washington	**57**	2		13	
Oregon	10	**29**	1	17	
California	32	66	**99**	45	17
Idaho		3		**24**	
Nevada				1	**83**

Northward movement of gadwalls from California to Oregon may represent post-breeding molt migrations (Yarris et al. 1994).

Derivation of Harvest—Pacific Flyway hunters obtained 73% of their total dabbling duck harvest from Alaska and Canada, with 31% of total harvest coming from Alaska and 23% from Alberta (Table 4). Alaska was the most important source area for green-winged teal, pintails, wigeons, and shovelers; British Columbia was the most important source area for wood ducks; and Alberta was the most important source area for mallards. California was the most important source area for gadwalls and cinnamon teal. Oregon and Prairie U.S. were moderately important source areas for gadwalls (Table 4). The Pacific Flyway mallard harvest had especially diverse origins, with only 36% of the harvest coming from areas that have historically defined the western AHM mallard population (14, 6, and 16% from AK, OR, and CA, respectively), with another 14 and 3% coming from jurisdictions (BC, WA) that were recently incorporated into the western mallard population AHM (U.S. Fish and Wildlife Service 2016). Across all dabbling duck species, 44% of the Pacific Flyway harvest was derived from Alaska, Oregon, and California and another 10% from British Columbia and Washington.

Alaska hunters obtained 100% of their mallard and pintail harvest from Alaskan sources, with only trace amounts from Yukon/NWT. Sample sizes for green-winged teal,

TABLE 4.—Percent derivation of dabbling duck harvests for Pacific Flyway hunters from source areas throughout the Pacific and Central Flyways (columns). Trace amounts (<0.5%) were omitted to enhance readability.

	Pacific Flyway sources:								Mid-continent sources:		
Species[a]	**AK[b]**	**BC**	**WA**	**OR**	**CA**	**ID**	**NV,UT**	**YK,NT**	**AB**	**SK,MB**	**MT,ND,SD**	**Harvest**
AGWT	58	2	1	1	1	1	1	6	24	3	2	462,277
AMWI	41	2						31	19	4	2	349,044
NOPI	47			1	1		2	4	22	15	8	458,892
NOSH	46	1		4	5		1	2	19	2	21	57,047
MALL	14	14	3	6	16	5	9	3	26	1	5	1,019,813
GADW	1	5	3	21	29	2	19		8	2	10	129,127
CITE[c]		17	1	8	46	2	3		10	2	9	54,536
WODU		35	4	9	14	8	18		10		3	37,619
All	31	8	2	4	9	2	5	7	23	4	5	2,568,355

[a] AGWT: American green-winged teal, AMWI: American wigeon, NOPI: northern pintail, NOSH: northern shoveler, MALL: mallard, GADW: gadwall, CITE: cinnamon teal, WODU: wood duck.
[b] AK: Alaska; BC: British Columbia; WA: Washington; OR: Oregon; CA: California; ID: Idaho; NV,UT: Nevada and Utah; YK,NT: Yukon and Northwest Territories; AB: Alberta; SK, MB: Saskatchewan and Manitoba; MT,ND,SD: Montana, North Dakota, and South Dakota (U.S. Prairies).
[c] Harvest from mid-continent sources is predominantly blue-winged teal, harvest from remaining areas is presumed to be primarily cinnamon teal.

wigeons, and shovelers harvested in Alaska were below our minimum threshold of 25 recoveries, but 100% of these species' harvests were also of Alaskan origin. For British Columbia, 71% of pintail harvest came from Alaska, 10% from Northwest Territories, and 19% from Prairie Canada (AB and SK/MB combined); 61% of the British Columbia mallard harvest came from British Columbia, 23% came from Alaska, and 12% came from Prairie Canada. Sample sizes were below threshold level, but most of British Columbia's green-winged teal and wigeon harvest came from Alaska or Yukon/NWT, whereas wood duck harvest was derived entirely from British Columbia.

For Washington and Oregon hunters, Alaska was the most important source area for green-winged teal, wigeons, pintails, and shovelers (Table 5), and accounted for approximately one third of the total dabbler harvest for both states. Alberta accounted for 23−28% of the total dabblers harvested, with mallards, wigeons, and pintails representing the most important species. Contributions from other portions of the Prairie Pothole Region were negligible. Yukon/NWT was an important region for wigeon production and British Columbia was the most important region for wood duck production. Modest proportions of shovelers, mallards, gadwalls, and wood ducks were produced within Washington and Oregon (Table 5).

California exhibited the most diverse derivation of harvest. Alaska and Prairie Canada demonstrated similar overall importance, with each region accounting for 28-29% of the overall dabbler bag of California hunters (Table 6). Alaska was most important for green-winged teal and northern shovelers, whereas Prairie Canada was most important for pintails. Most of California's mallard and gadwall harvest came from within-state production, making California the third most important production region for California hunters (Table

TABLE 5. —Percent derivation of dabbling duck harvests for Washington (top) and Oregon (bottom) from source areas throughout the Pacific and Central Flyways (columns). Trace amounts (<0.5%) were omitted to improve readability. Abbreviations as in Table 4.

	Pacific Flyway sources:						Mid-continent sources:			
Species	AK	BC	WA	OR	CA	ID	YK,NT	AB	SK,MB	MT,ND,SD	Harvest
Washington:											
AGWT	84	5	4			1	4	3			45,668
AMWI	51	3	1				34	10	1		63,567
NOPI	74	1		1			4	14	6	1	31,093
MALL	15	24	9	2		3	4	40	1	2	237,076
GADW		20	36	10	2			12		21	8,802
WODU		60	24	2		10				3	2,505
All	33	16	7	1		2	9	28	1	2	388,711
Oregon:											
AGWT	79	2	1	1		2	3	10		1	45,791
AMWI	34	7		1			28	25	4		57,631
NOPI	63	1		2			5	17	10	2	40,336
NOSH	71			29	1						12,137
MALL	11	16	2	24	4	3	3	33	1	4	148,757
GADW		5	1	54	36			4			11,616
WODU		28	6	39		20				7	8,285
All	32	10	1	16	3	2	7	23	3	3	324,553

6). Approximately 65% of California's combined harvest of cinnamon and blue-winged teal came from areas where cinnamon teal predominate (especially from California), 20% came from the Canadian and U.S. prairies where blue-winged teal predominate, and the remaining 15% came from northern portions of the Pacific Flyway (BC, WA, ID) where both species can co-occur. Northwest Territories was the most important source area for wigeons and British Columbia was the most important source area for wood ducks. Remaining production regions all contributed modestly for at least one species (Table 6).

More than half of Nevada's total dabbler harvest was estimated to have been produced in Nevada; green-winged teal and pintails were exceptions to this pattern, coming primarily from Alaska and Canada (Table 6). Idaho and Utah harvests were more dependent on birds from Prairie Canada (especially Alberta) and less dependent on birds from Alaska and western Canada (BC, NT/YK); however, Alaska still contributed substantially to green-winged teal and pintail harvests in both states (Table 7). A large portion of the mallards and wood ducks harvested in Idaho, and mallards and gadwalls harvested in Utah, were derived from within-state production. Utah was the only Pacific Flyway state where production origins for teal suggested that the harvest was predominantly blue-winged teal rather than cinnamon teal. Yukon/NWT was important for wigeon harvest in both states, and British Columbia was important for wood duck harvest in Idaho (Table 7). Proximity to the U.S. Prairie Pothole Region was somewhat important for pintail, mallard, and gadwall harvest in both states.

Table 6. —Percent derivation of dabbling duck harvests for California and Nevada from source areas throughout the Pacific and Central Flyways (columns). Trace amounts (<0.5%) were omitted to improve readability. Abbreviations as in Table 4.

	Pacific Flyway sources:							Mid-continent sources:				
Species	AK	BC	WA	OR	CA	ID	NV,UT	YK,NT	AB	SK,MB	MT,ND, SD	Harvest
California:												
AGWT	53	2	1	1	1	1	1	6	28	4	3	278,463
AMWI	28	2	1	1				34	26	5	2	162,385
NOPI	35			1	1		2	5	27	19	9	308,566
NOSH	41			6	9		1	2	21	4	14	142,321
MALL	1	5	1	6	60	1	6	1	14	1	3	275,356
GADW		2	1	25	49		11		7	1	2	67,233
CITE[a]		12		8	53	2	3		10	1	10	41,071
WODU		32	3	11	28	7	2		12		5	22,931
All	28	3	1	4	19	1	3	7	22	7	6	1,298,326
Nevada:												
AGWT	35						5	27	27	5	1	12,088
NOPI	31						13	4	18	26	9	8,718
MALL				1			89	1	5	1	2	21,543
GADW				21	4		75					7,176
WODU						1	99					308
All	14			3	1		53	8	12	6	3	49,833

[a] Harvest from Prairie Canada and U.S. is predominantly blue-winged teal; harvest from remaining areas is presumed to be primarily cinnamon teal.

We evaluated temporal changes in derivation of Pacific Flyway total harvest for mallards, gadwalls, and northern pintails, which had the most extensive recovery data (Appendix 3). Harvest proportions of gadwalls from California and the U.S. Prairies tripled during the second half of our study (Figure 3a), likely due to increased breeding populations. Because total gadwall harvest grew by 44% during this time, apparent declines in derivation from remaining areas in the Pacific Flyway represent lack of similar growth in harvest rather than true declines. For pintails, approximately one third of the total harvest derivation shifted from the Canadian Prairies to Alaska (Figure 3b), while total harvest remained relatively constant. Mallards exhibited an approximate doubling of harvest derivation from California, Nevada, Utah, and the U.S. Prairies (Figure 3c), concurrent with extensive population growth in these same areas. Harvest derivation of mallards from British Columbia declined substantially during the second half of our study, but this was apparently not due to declining populations of mallards in British Columbia (BBS-based population estimates declined by ~10% during this period), but rather due to concurrent decline in mallard harvest from British Columbia (Olson 2014).

Table 7.—Percent derivation of dabbling duck harvests for Idaho and Utah from source areas throughout the Pacific and Central Flyways (columns). Trace amounts (<0.5%) were omitted to improve readability. Abbreviations as in Table 4.

	Pacific Flyway sources:						Mid-continent sources:				
Species	**AK**	**BC**	**OR**	**CA**	**ID**	**NV,UT**	**YK,NT**	**AB**	**SK,MB**	**MT,ND,SD**	**Harvest**
Idaho:											
AGWT	63				1		21	6	2	5	14,152
AMWI	23		1				44	25	2	4	18,156
NOPI	50				2	3	8	12	16	10	8,008
MALL	1	10	1		21	1	4	42	4	15	168,907
GADW			29		7	1		43	7	13	7,503
WODU		36	4	1	34			25		1	2,589
All	9	8	2		17	1	8	38	4	13	219,315
Utah:											
AGWT	35	1			2	1	7	46	5	1	41,871
AMWI						4	48	29	12	7	15,905
NOPI	30		1		1	8	5	24	14	17	35,256
MALL	1				5	60	2	17	3	9	73,212
GADW			3	1	6	55		6	2	25	24,332
CITE[a]				7	17	16		33	17	9	7,274
All	13		1		4	31	7	24	7	11	197,850

[a] Harvest from Prairie Canada and U.S. is predominantly blue-winged teal, harvest from remaining areas is presumed to be primarily cinnamon teal.

Discussion

Patterns of Harvest Distribution and Derivation—Over the last 50 years, Alaska produced 31% of the total Pacific Flyway dabbling duck harvest and Alberta produced 23%. Averaged over all species, 44% of the estimated Pacific Flyway dabbling duck harvest was derived from areas that contributed population data for the western mallard population AHM model during 2008−2016 (i.e., Alaska, Oregon, and California) and 10% was derived from areas added to the model in 2017 (British Columbia and Washington; U.S. Fish and Wildlife Service 2016). Of the remainder, 7% came from other production areas within the Pacific Flyway and 39% came from mid-continent sources (especially Alberta).

Over the last 50 years, mallards have comprised approximately 40% of the Pacific Flyway dabbling duck harvest; northern pintails, American green-winged teal, and American wigeons have collectively comprised half of the total dabbler harvest; and gadwalls, shovelers, cinnamon teal, blue-winged teal, and wood ducks have accounted for the remaining 10%. During this period, we found that mid-continent sources accounted for 35% of the total mallard harvest, with remaining states and provinces within the Pacific Flyway accounting for sizeable fractions of the total harvest (see also Munro and Kimball 1982, Giudice 2003). Because such a large component of the harvest was from mid-continent sources, we recom-

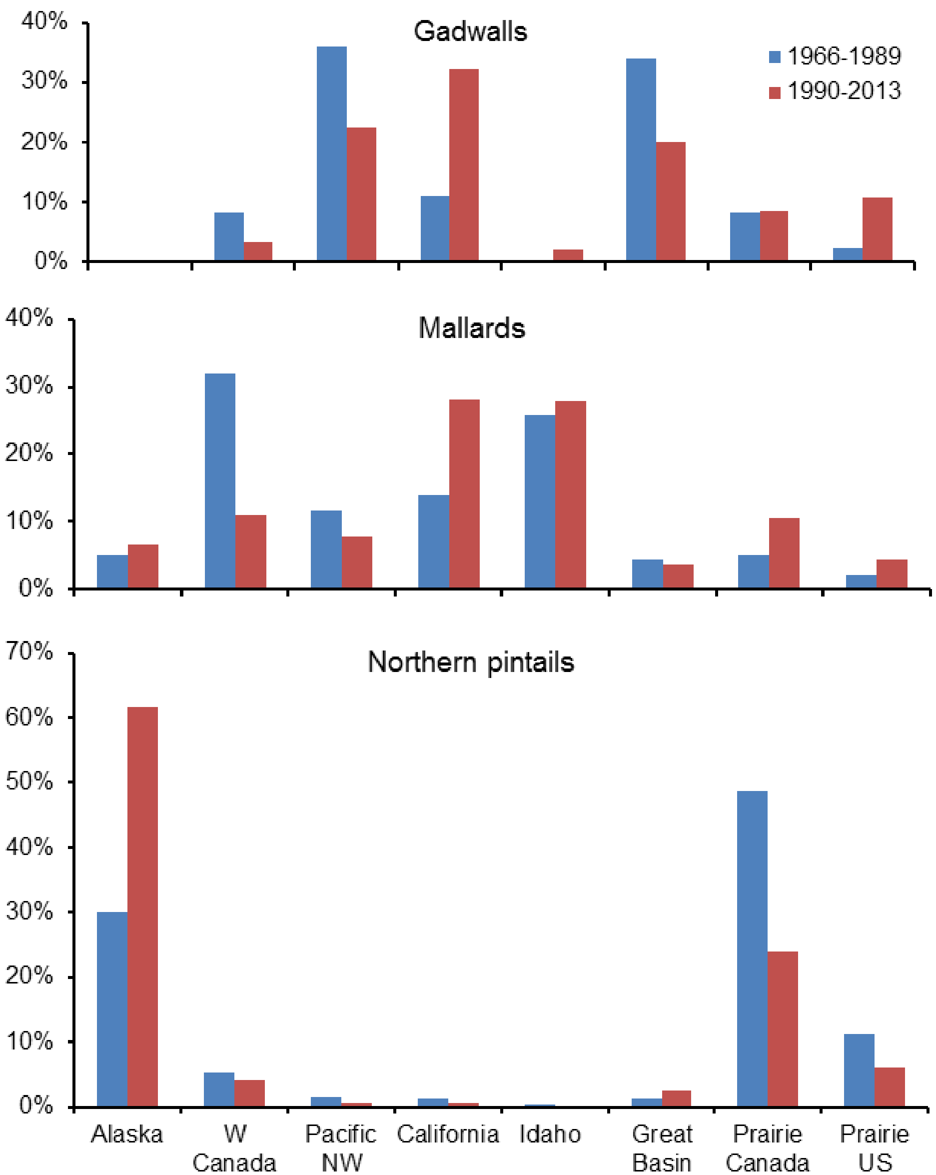

FIGURE 3.—Regional changes in harvest derivation for the Pacific Flyway between 1966-1989 and 1990-2013 (W Canada includes Yukon, Northwest Territories, and British Columbia; Pacific NW includes Washington and Oregon; Great Basin includes Nevada and Utah; Prairie Canada includes Alberta, Saskatchewan, and Manitoba; and Prairie US includes Montana, North Dakota, and South Dakota). Between intervals, average annual gadwall harvest increased by 44% (from 110 to 158 thousand), mallard harvest declined by 13% (1,138 vs. 988 thousand), and northern pintail harvest increased slightly (208 vs. 213 thousand).

mend that analysts attempting to estimate the size of the western mallard population using Lincoln estimators use harvest derivation as a correction factor (Alisauskas et al. 2014); our analysis suggests multiplying the Pacific Flyway total mallard harvest by 0.65 to remove mid-continent contributions. Although within-state production was an important part of the total mallard harvest in nearly all Pacific Flyway jurisdictions, migrant populations provided half or more of the total mallard harvest in Washington, Oregon, and Idaho. For all states except Alaska, greater than 60% of the harvest distribution for mallard populations occurred within the home state, and in California and Utah more than 90% of the total harvest was from the home state. For state waterfowl managers interested in maximizing harvest potential from migrant stocks, while concurrently sustaining breeding populations within their state, we recommend continuation of banding programs to monitor harvest rates of resident breeding mallards.

In addition to mallards, hunters within the Pacific Flyway also obtained large portions of the total gadwall, cinnamon teal, and wood duck harvest from production that occurred within the flyway, and often from within the home state or province. For example, Oregon, California, Nevada, and Utah all obtained half or more of their estimated gadwall harvests from within-state production, especially during the second half of our study period. Although many early studies explored the importance of local duck production in Pacific Flyway states (e.g. Williams and Marshall 1938, Harris 1954, Hunt and Naylor 1955, Steel et al. 1956), this seems to have been temporarily forgotten until the seminal paper by McLandress et al. (1996) examining recent mallard productivity in California rekindled interest in regional nesting studies (e.g., Gazda et al. 2002, Dugger et al. 2016, Ringelman et al. 2016).

Alaska was the most important production area for green-winged teal, wigeons, pintails, and shovelers, accounting for 40-60% of the total harvest for each species. Prairie Canada was the second most important production area for these four species, although Northwest Territories was more important for wigeons and Prairie U.S. was of equal importance for shovelers. Our analysis also identified small within-state contributions to harvest derivation for these species, and we were initially skeptical that these represented bandings of early migrants from northern production areas. However, historical nesting studies consistently identified small nesting populations of these species in lower 48 Pacific Flyway states (Williams and Marshall 1938, Harris 1954, Hunt and Naylor 1955, Steel et al. 1956).

Historically, the Canadian Prairies produced the majority of pintails harvested in the Pacific Flyway, but in recent decades pintail harvest has been derived predominantly from Alaska, presumably in response to long-term declines in pintail breeding productivity in the Canadian Prairies (Mattsson et al. 2012). There were too few banding data for green-winged teal and wigeons to examine whether similar shifts had occurred in their harvest derivations, but pintails are notable for demonstrating substantial population declines in the traditional prairie survey area even as most other species of dabbling ducks were increasing (Mattsson et al. 2012).

Data Limitations and Assumptions—The ability to reliably estimate direct recovery rates is the most limiting factor in any analysis of harvest distribution and derivation, and our analysis was hampered by availability of banding data for green-winged teal, American wigeons, northern shovelers, and cinnamon teal. Relative to their total population size, wigeons and shovelers had the fewest preseason bandings of any species, with each direct recovery recorded in the harvest representing >13,000 birds in the wild (by contrast, each direct mallard recovery represented ~200 birds in the breeding population). For wigeons, estimation of harvest derivation from Alaska, Yukon, and Northwest Territories over all Pacific Flyway states was based on fewer than 200 total band recoveries. In contrast, banding effort was extremely good for all species in Washington, Oregon, California, and Idaho.

The second key data requirement for analysis of harvest derivation is reliable data on population size from each production area. Although most states within the Pacific Flyway have their own dedicated waterfowl surveys (Olson 2014), the extent to which these surveys are comparable is unknown. Breeding Bird Surveys (BBS) are conducted using consistent methodology in all states and provinces of the U.S. and Canada, and although the BBS survey shows a general concordance with results from state and federal surveys, correction factors varied by more than two orders of magnitude among species and survey regions (Figure 2). We used estimates based on BBS routes, with a conservative visibility correction factor of 3.6, to impute population estimates for Idaho, which has no state survey, and for British Columbia, which has estimates for mallards and total ducks beginning in 2006. For Utah and Nevada, estimates from state waterfowl surveys were substantially lower than estimates derived from the BBS, even without visibility correction adjustments, and we therefore elected to use BBS-based estimates of population size for these two states. For Alaska and Yukon Territory, where the WBPHS covers only a small portion of the total area, abundance of widely distributed species like mallards and green-winged teal might be underestimated substantially. We believe there is much work that could be done to improve estimates of waterfowl population sizes throughout North America, including areas that have not traditionally been surveyed using dedicated waterfowl surveys, by combining data from multiple data streams including traditional BPOP surveys, BBS routes, and Lincoln estimators (Alisauskas et al. 2014, Zimmerman et al. 2015).

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Appendix 1.—Average annual breeding population estimates (thousands) for Pacific and Central Flyway source areas, 1990-2013, derived from state or federal waterfowl surveys (BPOP) or Breeding Bird Survey routes (BBS).

Region	Survey	AGWT	AMWI	NOPI	NOSH	BWTE	MALL	GADW	CITE	WODU
Pacific Flyway										
Alaska	BPOP	670	774	959	505	1	544	3	NA	NA
	BBS	57	157	42	26	1	66	1	1	0
Yukon	BPOP	15	73	29	15	0	15	0	NA	NA
	BBS	3	6	1	2	1	7	1	0	0
Brit. Columbia	BBS	6	10	1	2	6	97	4	3	3
Washington	BPOP	4	5	1	7	NA	57	14	6	2
	BBS	0	1	0	2	1	21	3	2	1
Oregon	BPOP	6	6	6	23	NA	92	51	36	5
	BBS	1	1	1	1	0	27	12	4	1
California	BPOP	4	5	11	33	NA	375	84	41	8
	BBS	0	1	6	12	0	154	60	19	7
Idaho	BBS	2	2	1	1	0	26	6	4	1
Nevada	BPOP	0	0	1	1	NA	3	7	6	0
	BBS	2	1	5	2	0	34	11	11	1
Utah	BPOP	0	0	1	4	NA	9	8	7	0
	BBS	3	4	5	2	0	26	18	11	0
Central Flyway										
NWT	BPOP	384	501	137	89	26	384	13	NA	NA
	BBS	38	64	17	13	8	39	6	0	0
Alberta	BPOP	682	399	326	654	754	1469	437	NA	NA
	BBS	26	41	54	93	125	470	87	5	0
Saskatchewan	BPOP	463	353	645	1055	1727	2281	887	NA	NA
	BBS	36	57	101	157	226	733	138	1	1
Manitoba	BPOP	160	109	57	149	389	736	113	NA	NA
	BBS	11	6	21	25	71	381	20	0	6
Montana	BPOP	28	78	108	117	131	311	171	NA	NA
	BBS	3	13	9	9	11	73	22	3	1
Wyoming	BBS	3	1	3	1	3	34	6	2	0
Colorado	BBS	3	1	1	1	2	41	8	3	0
North Dakota	BPOP	58	70	353	516	1458	1173	711	NA	NA
	BBS	5	8	40	42	111	272	91	0	3
South Dakota	BPOP	50	49	237	299	1346	824	439	NA	NA
	BBS	1	3	11	8	44	106	29	0	2

Appendix 2.—Region and species specific visibility correction factors, calculated as BPOP:BBS for regions with two concurrent surveys.

Region	AGWT	AMWI	NOPI	NOSH	BWTE	MALL	GADW	CITE	WODU	Region
Alaska	11.8	4.9	22.7	19.4	1.1	8.3	2.2			10.0
Yukon	4.3	11.8	20.4	8.6		2.1				6.7
Washington	13.3	6.5	11.0	3.9		2.7	4.9	2.9	1.6	5.9
Oregon	11.4	8.4	6.0	19.1		3.4	4.4	8.7	3.2	8.1
California	12.7	7.8	1.9	2.8		2.4	1.4	2.1	1.1	4.0
Nevada	0.1	0.7	0.1	0.3		0.1	0.6	0.5	0.1	0.3
Utah	0.1		0.2	1.6		0.4	0.4	0.6		0.4
NWT	10.0	7.8	7.9	6.9	3.1	9.8	2.0			6.8
Alberta	26.2	9.7	6.0	7.0	6.0	3.1	5.0			9.0
Saskatchewan	12.9	6.2	6.4	6.7	7.6	3.1	6.4			7.0
Manitoba	14.3	18.5	2.7	6.0	5.5	1.9	5.8			7.8
Montana	11.2	6.2	12.5	13.1	12.0	4.3	7.7			9.6
North Dakota	12.0	9.3	8.8	12.4	13.2	4.3	7.8			9.7
South Dakota	55.8	15.3	22.2	37.4	30.4	7.8	15.0			26.3
Spp. Avg.	14.0	8.1	9.2	10.4	8.8	3.8	4.6	3.0	1.2	7.8

APPENDIX 3.—Preseason bandings (B) and direct recoveries (R) of dabbling ducks from Pacific Flyway production areas, 1966-2013, all ages and sexes combined.

		Banding Areas:										
Species		AK	BC	WA	OR	CA	ID	NV,UT	NT,YK	AB,SK,MB	MT,ND,SD	Total
MALL	B	15,067	28,798	46,058	123,171	194,875	60,944	19,451	54,161	1,127,297	257,065	1,926,887
	R	838	1,796	4,516	11,548	18,698	4,593	2,256	599	12,036	1,187	58,067
NOPI	B	58,263	901	698	3,843	3,513	1,107	13,050	57,401	221,188	27,637	387,601
	R	1,902	17	22	154	119	40	342	709	2,962	199	6,466
AGWT	B	21,875	875	579	1,637	130	361	821	15,287	48,451	5,592	95,608
	R	811	28	34	90	11	12	19	80	266	38	1,389
AMWI	B	356	105	57	375	90	52	15	722	5,173	1,754	8,699
	R	73	24	8	78	12	5	2	109	308	49	668
GADW	B	26	296	546	24,958	12,073	241	2,753	8	18,560	9,686	69,147
	R	2	28	39	3,167	1,377	7	255	0	29	12	4,916
NOSH	B	889	41	69	3,098	349	39	423	122	1,951	3,957	10,938
	R	62	2	6	233	23	0	20	2	19	27	394
CITE	B	0	122	98	1,229	5,998	502	2,317	0	1,210	148	11,624
	R	0	0	1	10	229	9	31	0	2	0	282
BWTE	B	40	856	109	219	29	286	54	856	667,763	180,426	850,638
	R	0	8	0	6	0	1	0	0	60	8	83
WODU	B	0	815	2,424	6,540	10,431	5,457	265	0	1,904	11,734	39,570
	R	0	56	194	442	560	412	20	0	5	18	1,707
Total	B	95,516	32,809	50,638	165,070	227,488	68,989	39,149	128,557	2,093,497	497,999	3,400,712
	R	3,688	1,959	4,820	15,728	21,029	5,079	2,945	1,499	15,687	1,538	73,972