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Surveys of Waterfowl in Kachemak Bay, Alaska During Winter 1999–2019

Michael R. Guttery, Mike J. Petrula, Jason L. Schamber, Tasha J. DiMarzio, Tyler L. Lewis, William W. Larned, and Heather M. Wilson

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Alaska Department of Fish and Game Division of Wildlife Conservation

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Michael R. Guttery
Mike J. Petrula
Jason L. Schamber
Tasha J. DiMarzio
Tyler L. Lewis
Alaska Department of Fish and Game
Division of Wildlife Conservation
Waterfowl Program
333 Raspberry Road
Anchorage, Alaska 99518-1599
michael.guttery@alaska.gov
(907) 267-2159

William W. Larned
Heather M. Wilson
U.S. Fish and Wildlife Service
Alaska, Migratory Bird Management
Waterfowl Division
1011 East Tudor Road Suite 200
Anchorage, Alaska 55903

Alaska Department of Fish and Game
Division of Wildlife Conservation
PO Box 115526
Juneau, AK 99811-5526

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Abstract

In response to public concern over perceived declines in sea duck populations in Kachemak Bay, Alaska, the Alaska Department of Fish and Game Waterfowl Program began conducting waterfowl surveys of the bay during winter of 1999. Between 1999 and 2019, a total of 10 surveys were conducted. Each survey included the use of open skiffs to enumerate waterfowl using nearshore habitats and fixed-winged aircraft to survey transects in offshore areas. Initially we had hoped to produce abundance estimates by species, but it was determined that the complexities of surveying wintering waterfowl precluded us from achieving this level of inference. Consequently, we report the results of trend analyses for those species for which there was adequate data. Results suggest that overall sea duck and total duck (sea ducks plus dabbling ducks) numbers increased over the course of the survey. Of the 10 individual species for which there was adequate data for analysis, 7 were found to have positive population trajectories. Population declines were detected for goldeneye (species combined), long-tailed ducks, and mallards with varying degrees of certainty. Overall, our results suggest that duck and sea duck populations are generally doing well in Kachemak Bay. However, it is important to note that due to their migratory nature, sea ducks, like virtually all waterfowl species, are typically monitored and managed at very large spatial scales so it is unclear how or if these results are indicative of patterns occurring at management-relevant scales.

Key words: lower Cook Inlet, Southcentral Alaska, sea ducks, population distribution, American green-winged teal, *Anas carolinensis,* American wigeon, *Mareca americana,* Barrow's goldeneye, *Bucephala islandica,* black scoter, *Melanitta americana,* bufflehead, *Bucephala albeola,* common eider, *Somateria mollissima,* common goldeneye, *Bucephala clangula,* common merganser, *Mergus merganser,* greater scaup, *Aythya marila,* harlequin duck, *Histrionicus histrionicus,* king eider, *Somateria spectabilis,* lesser scaup, *Aythya affinis,* long-tailed duck, *Clangula hyemalis,* mallard, *Anas platyrhynchos,* northern pintail, *Anas acuta,* red-breasted merganser, *Mergus serrator,* Steller's eider, *Polysticta stelleri,* surf scoter, *Melanitta perspicillata,* white-winged scoter, *Melanitta deglandi.*

Introduction

Waterfowl comprise a substantial portion of the total marine bird community inhabiting Kachemak Bay, Alaska in winter (Agler et al. 1995). Among the waterfowl inhabiting Kachemak Bay, sea ducks are the most abundant species group (Erikson 1977, Agler et al. 1995). For regulatory purposes, the Alaska Department of Fish and Game (ADF&G) classifies the following species as sea ducks in Alaska: harlequin ducks, long-tailed ducks, common eiders, king eiders, surf scoters, white-winged scoters, black scoters, common mergansers, red-breasted mergansers, and hooded mergansers (note that bufflehead, Barrow's, and common goldeneye are not classified as sea ducks in Alaska regulations despite their taxonomic classification as sea ducks).

The status of sea duck populations is of concern to waterfowl managers throughout North America, having decreased by approximately 30% since the 1970s. In contrast, dabbling and diving duck populations have increased by 34% over the same time period (North American Bird Conservation Initiative 2022). However, available evidence suggests abundance trends may vary widely across sea duck species, from stable to increasing, to decreasing, with varying degrees of certainty across North American species (Bowman et al. 2015). Inadequate and/or imprecise quantitative information on abundance, breeding ecology, migration routes, and harvest rates for many species of sea ducks have limited the ability of waterfowl managers to accurately assess current trends for these populations. As a result, research and monitoring projects have been conducted throughout North America where sea ducks nest, molt, and overwinter.

Sea ducks, like all species of waterfowl in North America, are monitored and managed at large spatial scales (e.g., state, flyway, continent). However, in some cases it can be informative to monitor populations at smaller scales. In response to the accessibility of Kachemak Bay to sport hunters and public interest in sea ducks, the Alaska Department of Fish and Game Waterfowl Program conducted periodic winter surveys in Kachemak Bay during 10 years between 1999 and 2019. The surveys were conducted during early to mid-March because 1) waterfowl numbers are relatively stable in winter compared to periods of migration (spring and fall), 2) a greater number and diversity of waterfowl are present during the winter, 3) numbers and composition reflect waterfowl occurrence during and after the hunting season, and 4) it is impractical to conduct surveys from November through February due to limited daylight and winter storms that occur during this time.

Our initial goal was to obtain estimates of abundance for waterfowl species, particularly sea ducks, utilizing Kachemak Bay during late winter. However, our survey design did not allow us to adequately account for likely sources of observation error in counts (both imperfect detection and double counting of birds). Consequently, we present results in the form of an index of abundance and associated temporal trends in the indices. Trends were evaluated for species encountered most frequently. Information derived from these surveys will be a valuable addition to our understanding of sea duck populations and management needs in the Kachemak Bay region of Southcentral Alaska.

Study Area and Methods

Waterfowl surveys were conducted in Kachemak Bay, located on the eastern shore of lower Cook Inlet (LCI), Alaska (Fig. 1) in 1999–2003, 2012–2014, and 2018–2019. We divided

Figure 1. Location of Kachemak Bay in lower Cook Inlet, Alaska shown in red. Winter sea duck surveys, both aerial and boat-based shoreline surveys, were conducted throughout Kachemak Bay in 1999–2003, 2012–2014, and 2018–2019 by the Alaska Department of Fish and Game (boat-based surveys) and U.S. Fish and Wildlife Service (aerial surveys).

Kachemak Bay into 2 strata; shoreline and offshore. The shoreline stratum was defined as all waters within 200 m of land from Anchor Point to Point Pogibshi (Fig. 2). Land included the mainland, islands, spits, and exposed rocks. The entire shoreline stratum was surveyed from 2 open skiffs (ca. 6 m long) traveling 5–10 km/hr. Boat crews consisted of one primary observer, a data collector, and a boat driver who also served as a secondary observer. Only waterfowl on shore or within the 200 m buffer were recorded as being in the shoreline stratum. We disregarded the 200 m buffer in several small bays, coves, and lagoons because it was possible to obtain counts of the entire area.

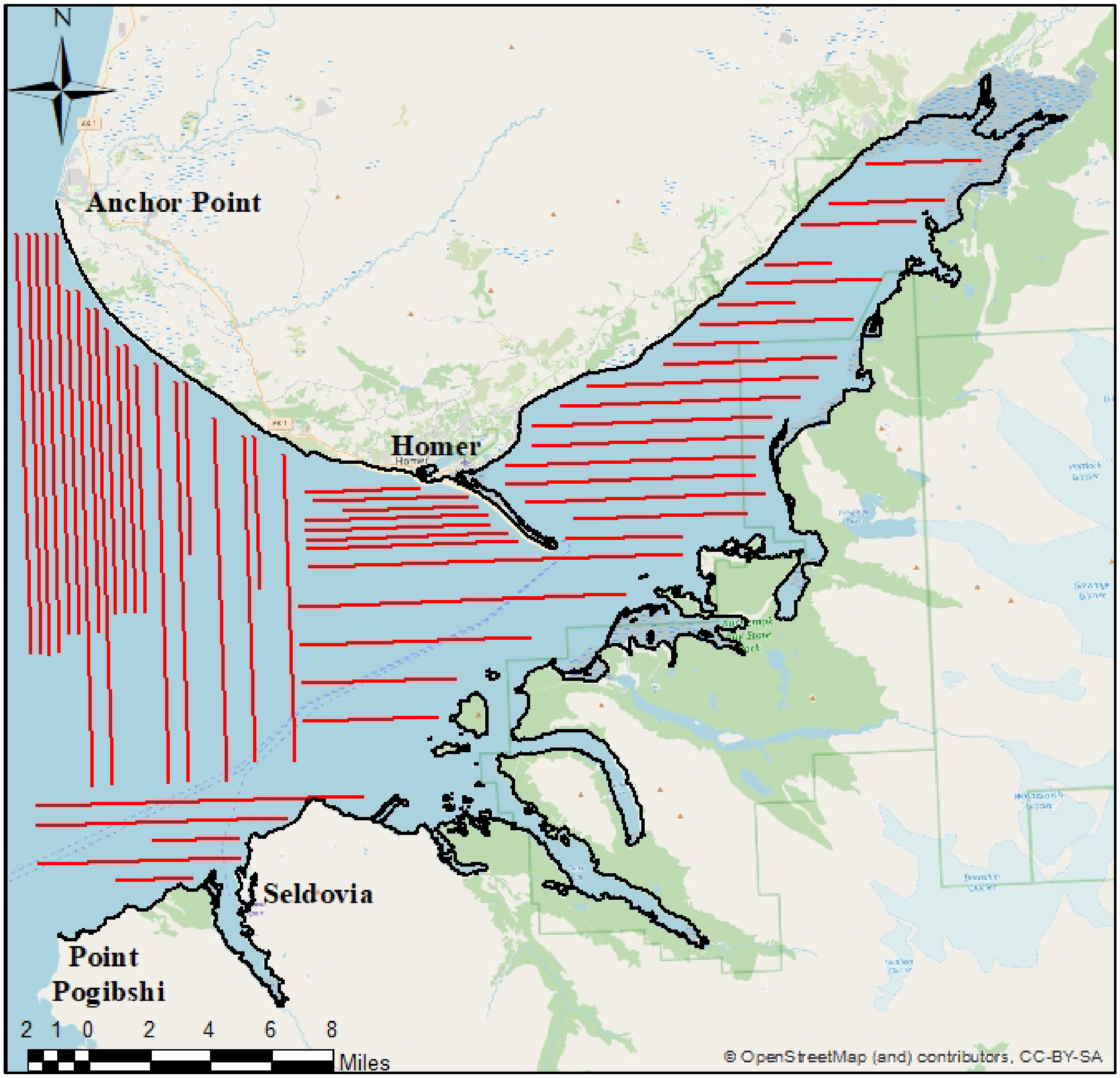
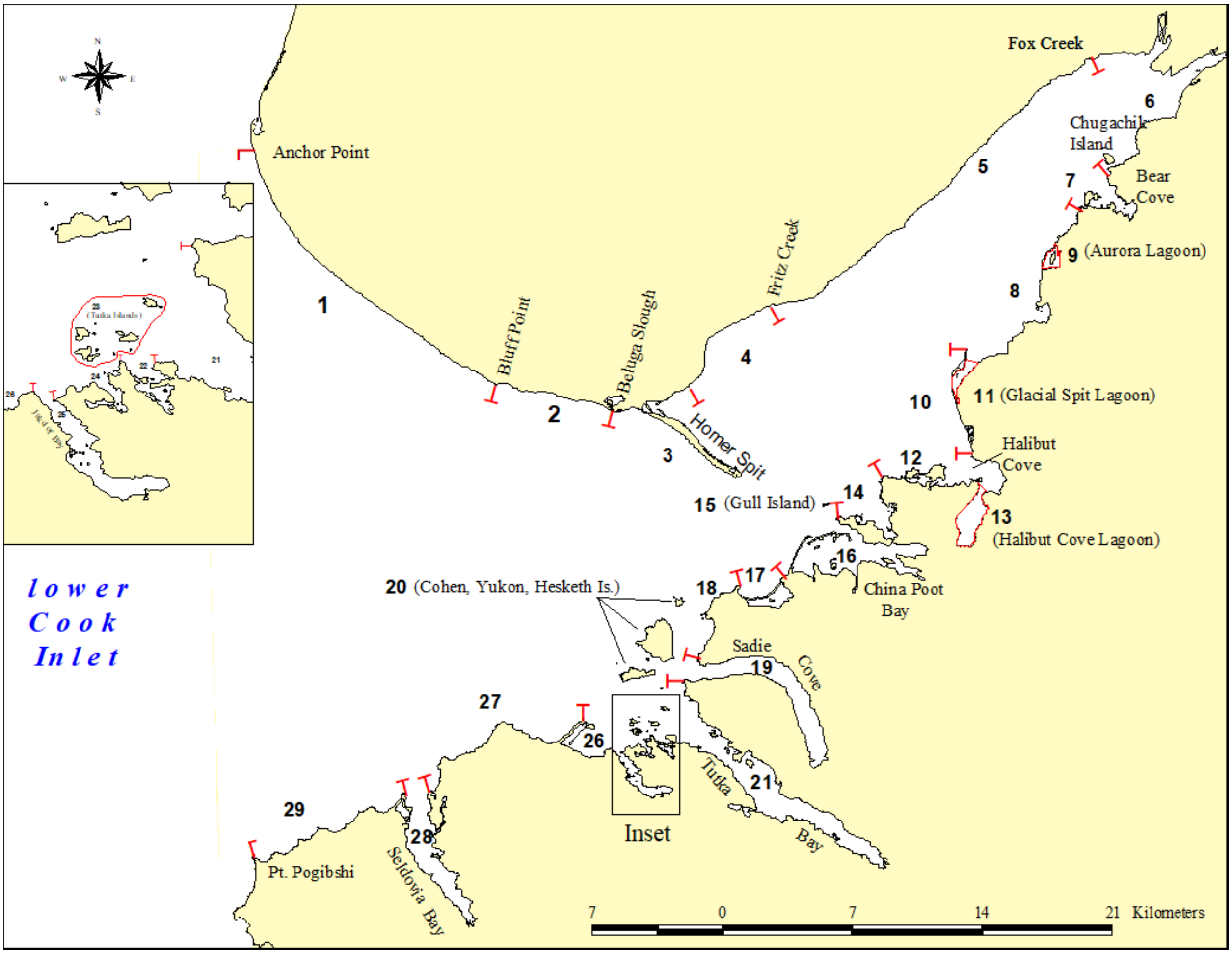


Figure 2. Kachemak Bay shoreline survey route (black line, boat surveys) and offshore transects (red lines, aerial surveys) conducted during winters of 1999–2003, 2012–2014, and 2018–2019. Note that boat-based surveys were conducted by ADF&G and aerial surveys by the U.S. Fish and Wildlife Service, Migratory Bird Management, Waterfowl Division.

The shoreline stratum was subdivided into 29 shoreline segments (Fig. 3) based on easily identifiable landmarks to facilitate the sampling of discrete areas. Shoreline surveys were conducted throughout daylight hours during all phases of the tide cycle. Due to variable weather conditions, not all shoreline segments were surveyed in all years.



Produced by ADF&G, using ArcView™ software (Esri, Redlands, California).

Figure 3. Shoreline segments used to survey wintering sea ducks in Kachemak Bay, Alaska, 1999–2003, 2012–2014, and 2018–2019. Survey segments are numbered and delineated by the red symbols.

The offshore stratum included all waters within Kachemak Bay outside the shoreline stratum bounded on the west by long 151° 55′ 00″ (Fig. 2). The offshore stratum was surveyed from a Cessna 206 fixed-winged, amphibious aircraft flying at an altitude of ca. 150 ft and an air speed of ca. 80–90 knots. The pilot and right-seat observer recorded all waterfowl on each side of the aircraft within 200 m of the line of travel. A moving map program (John Hodges, USFWS Migratory Bird Management, Juneau, Alaska) was used to project transect locations and record waterfowl observations. The map program was linked to the onboard GPS (Global Positioning System) receiver to record precise observation locations and flight paths. Survey of the offshore stratum took ca. 4–6 hours and was completed in a single day during most years.

In 1999 and 2000, we surveyed randomly selected 5 km flightlines throughout Kachemak Bay ($n = 30$ and $n = 60$, respectively), providing 8.6% and 13.4% survey coverage of the offshore stratum, respectively. In 2001, flight lines were systematically located and oriented to maximize survey coverage and flight time efficiency ($n = 35$; Fig. 2). These systematically located flight lines were used in all subsequent years. In 2003, 16 additional flight lines were added and used in subsequent years for a total of 51 potential flightlines, providing 31% coverage of all offshore waters. Due to inclement weather or other unanticipated delays, not all flight lines were surveyed in all years (Table 1).

Table 1. Percent of segments surveyed completely during waterfowl surveys of Kachemak Bay, Alaska, 1999–2019. The number of aerial segments available for survey varied across time.

Survey year	Percent of shoreline segments surveyed	Percent of aerial segments surveyed
1999	82.8	71.7
2000	96.6	100.0
2001	100.0	100.0
2002	96.6	96.8
2003	93.1	97.9
2012	100.0	91.5
2013	93.1	100.0
2014	93.1	100.0
2018	93.1	100.0
2019	86.2	100.0

Waterfowl were classified by species during all surveys. In cases of closely allied species that are difficult to distinguish from one another, we were only able to identify to the species group. For example, distinguishing Barrow's goldeneye (BAGO) from common goldeneye (COGO) was generally not possible during aerial surveys, so the 2 species were grouped together as goldeneye (GOLD). Initially, surveys were conducted under the assumption of perfect detection of waterfowl along shoreline segments and flight lines. With the realization that this assumption was likely violated, replicate surveys of some transects (both shoreline and aerial) were conducted in 2012, 2013, 2014, and 2018 in an attempt to estimate and rectify potential errors in the counts. However, the survey design did not account for observing the same bird(s) multiple times. Due to the infrequent occurrence of replicate surveys within years, and the inability to account for double counting, it is not possible to derive defensible abundance estimates with our data. It is conceivable that rates of imperfect detection and double counting may have varied across years, by survey type (shoreline or offshore), waterfowl species, and observers. Unfortunately, our data do not allow us to evaluate any of these possibilities. To address our primary objective of gaining insights into general population trajectories (increasing, stable, decreasing) by species over time, we assume that biases related to the observation process were constant across years, and consequently interpret our data and results as indices of abundance rather than true abundance estimates. In years when replicate surveys were conducted, we used data from the most complete survey round (when the greatest percentage of transects were surveyed).

We present basic descriptive statistics and figures relative to the spatial distribution (Fig. 4), total counts (Table 2), and representation in aerial and shoreline surveys (Fig. 5) by species or species group. Flock coordinates were converted to spatial rasters with 0.5 km^2 cells to portray observed density (Fig. 4). Flock coordinates were not recorded in 2000 or 2019 so maps do not include these years. These data are presented for illustrative purposes and no broader inference should be drawn from these results as they do not account for changes in survey design (different aerial transects were used in the first 2 years of the survey) or differential survey effort across years.

Table 2. List of all duck species detected during 10 winter waterfowl surveys conducted from 1999–2019 in Kachemak Bay, Alaska.

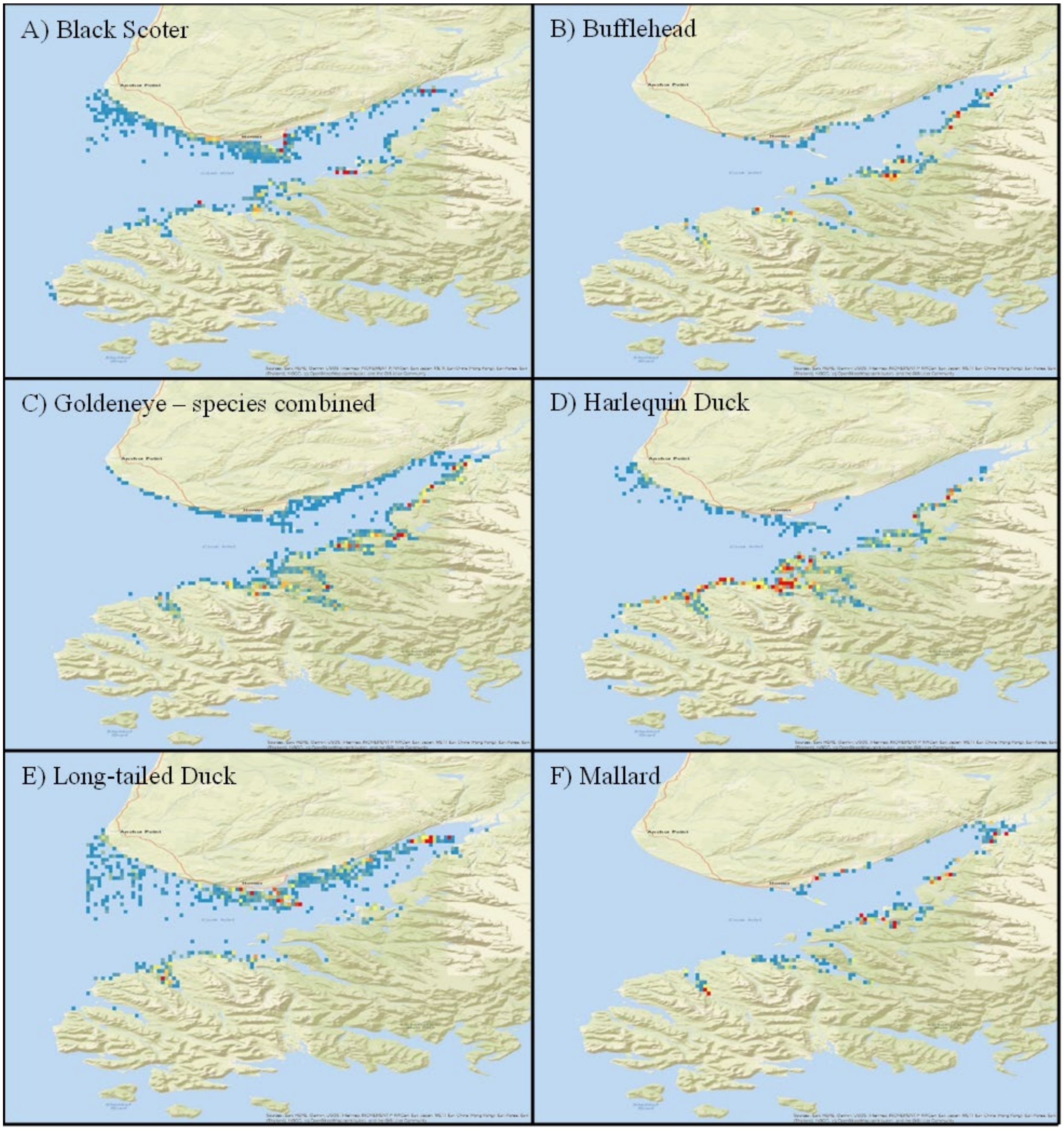
Code	Common name	Scientific name	Total count	Analyzed
AGWT	American green-winged teal	*Anas carolinensis*	39	No
AMWI	American wigeon	*Mareca americana*	55	No
BAGO[1]	Barrow's goldeneye	*Bucephala islandica*	30,780	Yes[1]
BLSC	black scoter	*Melanitta americana*	11,626	Yes
BUFF	bufflehead	*Bucephala albeola*	6,159	Yes
COEI	common eider	*Somateria mollissima*	821	No
COGO[1]	common goldeneye	*Bucephala clangula*	5,500	Yes[1]
COME[2]	common merganser	*Mergus merganser*	2,430	Yes[2]
GRSC[3]	greater scaup	*Aythya marila*	13,715	Yes[3]
HADU	harlequin duck	*Histrionicus histrionicus*	17,589	Yes
KIEI	king eider	*Somateria spectabilis*	31	No
LESC[3]	lesser scaup	*Aythya affinis*	2	Yes[3]
LTDU	long-tailed duck	*Clangula hyemalis*	4,009	Yes
MALL	mallard	*Anas platyrhynchos*	30,676	Yes
NOPI	northern pintail	*Anas acuta*	297	No
RBME[2]	red-breasted merganser	*Mergus serrator*	3,173	Yes[2]
STEI	Steller's eider	*Polysticta stelleri*	1,418	No
SUSC	surf scoter	*Melanitta perspicillata*	15,669	Yes
WWSC	white-winged scoter	*Melanitta deglandi*	12,899	Yes

Note: Presented in this table are alpha codes (code) used to abbreviate duck species names, scientific names, total raw number of individuals counted during all surveys combined (total count), and whether analyses were performed and presented for each species (analyzed, yes/no).

[1] In some instances, observers were unable to determine species, resulting in 4,981 individuals being classified under the general category of goldeneye (GOLD). For analysis, Barrow's goldeneye and common goldeneye were combined into the general goldeneye group for a total species group count of 41,261 birds.

[2] In some instances, observers were unable to determine species, resulting in 438 individuals being classified under the general category of merganser (MERG). For analysis, common merganser and red-breasted merganser were combined into the general merganser group for a total species group count of 6,041 birds.

[3] In some instances, observers were unable to determine species, resulting in 2,289 individuals being classified under the general category of scaup (SCAU). For analysis, greater scaup and lesser scaup were combined into the general scaup (SCAU) group for a total species group count of 16,006 birds.



Produced by ADF&G, using ArcMap™ 10.6.1 software (Esri, Redlands, California).

Figure 4. Spatial distribution and relative density of ducks detected during March aerial and shoreline surveys of Kachemak Bay, Alaska, 1999–2003, 2012–2014, and 2018–2019. Note that cooler (more blue) colors correspond to relatively low density, whereas hotter (more red) colors correspond to areas with higher density.

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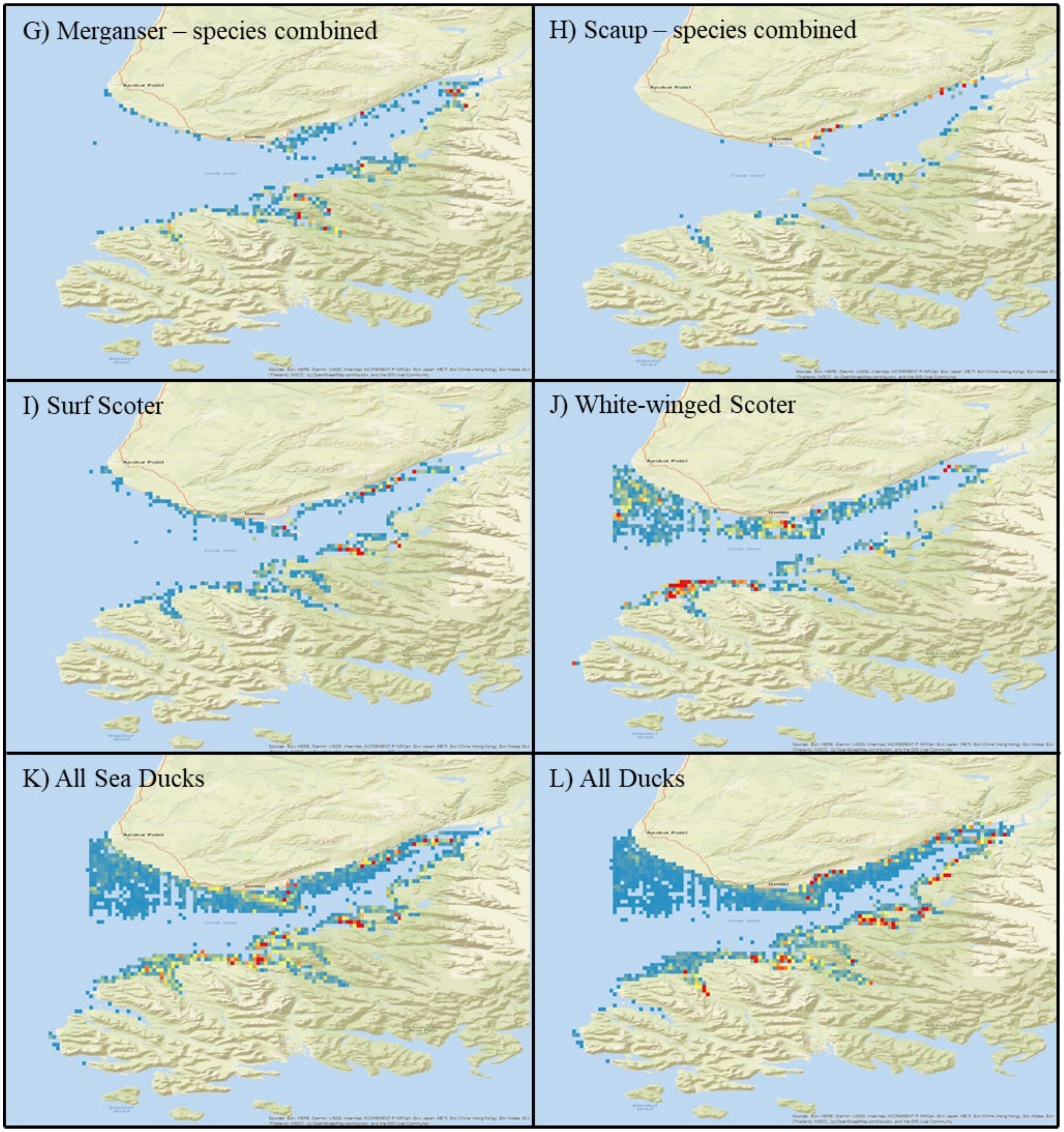

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Figure 4. Page 2 of 2. Note that cooler (more blue) colors correspond to relatively low density, whereas hotter (more red) colors correspond to areas with higher density.

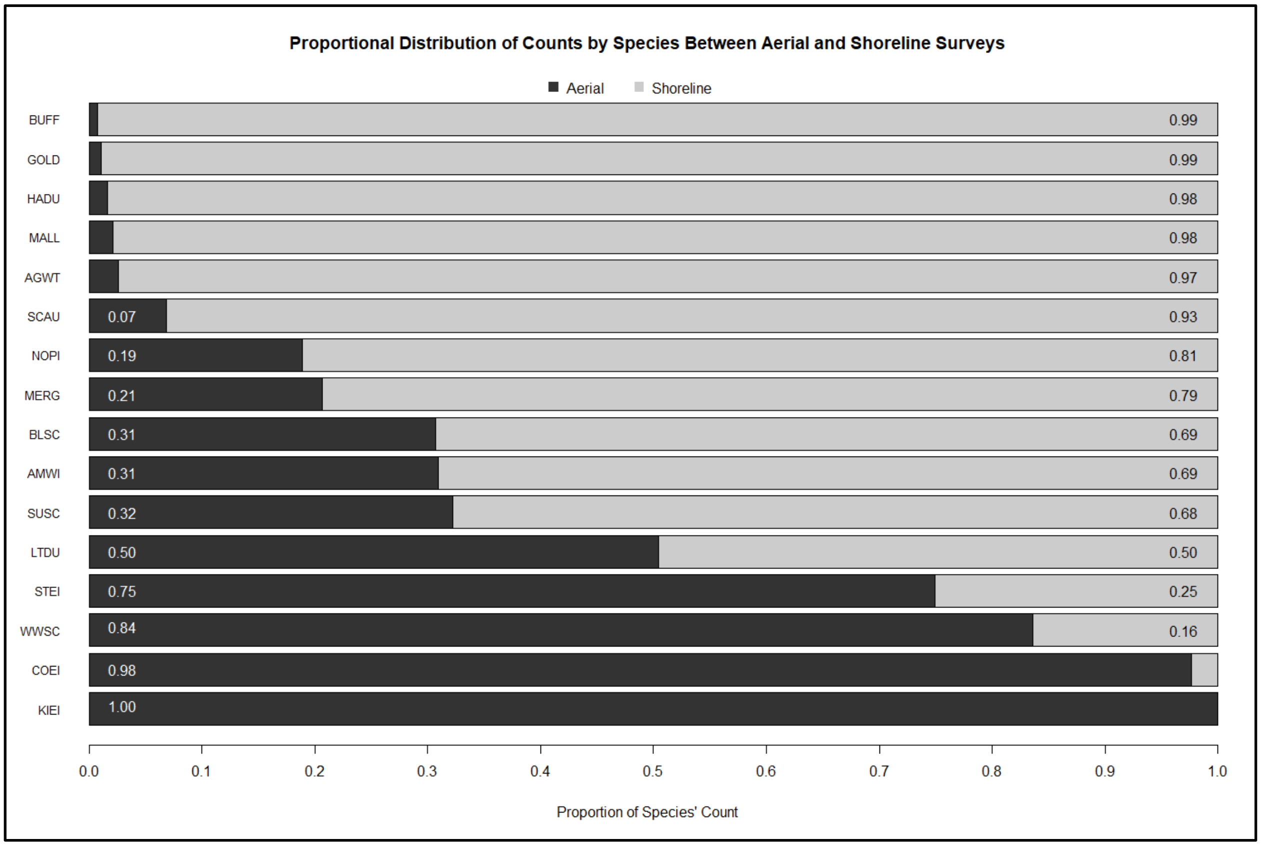

Figure 5. Proportional distribution of species-specific counts between aerial (offshore) and shoreline survey segments for March duck surveys in Kachemak Bay, Alaska, 1999–2019. See Table 2 for explanation of species alpha codes.

For our analysis of abundance indices, we began by collapsing the raw data such that the final data set contained a single value for the total number of birds observed by species (or species group) for each year and each transect. Eighteen segments were never surveyed and were therefore removed from the dataset, resulting in a final data set of 122 unique transects (shoreline and aerial combined). For the first stage of our analysis, we used a generalized linear mixed-effects regression model of the form

$$C_{ijk} \approx \alpha + \beta \times \text{Year}_j + \delta(\text{Transect}_k) + \varepsilon_{jk}$$

where C_{ijk} is the count for species i in Year j on Transect k, α is the global y-axis intercept parameter, β is the slope parameter for the effect of survey year, $\delta(\text{Transect}_k)$ is a vector of transect-level random intercept terms, and ε_{jk} is the residual error in the model. Counts for each species were modeled using Poisson, negative-binomial, and over-dispersed Poisson distributions. Model selection methods based on Akaike Information Criterion (AIC) were used to select the most appropriate count distribution for each species (Table 3). Using parameter estimates based on the best fitting distribution and the model described above, we then generated model-based predictions of counts at all 122 transects over the 21-year span between the first (1999) and last (2019) survey. We summed the predicted transect-level counts for each year to obtain the total predicted number of ducks of each species or group across all transects (aerial and shoreline).

For the second stage of our analysis, we calculated the average annual rate of change in the predicted count index for each species λ_{sp} as:

$$\lambda_{sp} = \bar{x}\left(\frac{\sum_{i=1}^{n} A_i(t+1)}{\sum_{i=1}^{n} A_i(t)}\right)$$

Where $A_i(t)$ = the predicted count for the given species on transect i in year t, summed across n = 122 transects, and the arithmetic mean taken of the vector of quotients. For presentation purposes, all annual abundance indices were converted to Z-scores to prevent values on the count scale from being incorrectly interpreted as true abundance estimates.

Table 3. Model selection results used to select the statistical distribution for analyzing counts of duck species or groups observed during March surveys in Kachemak Bay, Alaska, 1999–2019.

Species[1]	Selected distribution	Δ AIC – Poisson	Δ AIC – NegBin	Δ AIC – ODP
BLSC	NegBin	20,077.2	0.0	40.4
BUFF	ODP	1,825.5	10.1	0.0
GOLD	ODP	10,763.1	10.6	0.0
HADU	ODP	2,419.1	2.2	0.0
LTDU	NegBin	3,557.8	0.0	35.5
MALL	ODP	28,110.3	6.5	0.0
MERG	ODP	4,931.5	0.6	0.0
SCAU	ODP	15,964.1	–	0.0
SUSC	NegBin	15,464.9	0.0	20.8
WWSC	NegBin	9,477.0	0.0	34.0
Sea Ducks	NegBin	31,900.3	0.0	34.6
All Ducks	NegBin	52,184.9	0.0	58.6

Note: Statistical distributions considered include the Poisson, negative binomial (NegBin), and over-dispersed Poisson (ODP). For model selection, the statistical distribution which resulted in the lowest value of the Akaike Information Criterion (AIC) score was selected. For simplicity, we present the change in AIC score (Δ AIC) which is calculated by subtracting the minimum AIC score from all AIC scores for a species or group such that the statistical distribution with the lowest AIC score has a Δ AIC value of 0.0 and score for all other distributions are relative to the selected distribution. If model convergence was not achieved, the corresponding statistical distribution was discarded for that species/group and an en dash (–) was entered into the table.

[1] See Table 2 for an explanation of species alpha codes.

We initially ran all analyses using frequentist statistics in Program R (version 3.6.0) and used standard model selection criteria (AIC) to select the most appropriate response distribution (Poisson, negative binomial, or over-dispersed Poisson) for each species (Table 3). However, in order to fully propagate errors, we elected to implement the final analyses using Bayesian approaches. Models were run in JAGS (version 4.3.0), called from Program R (version 4.1.2) using the "jagsUI" package. We used diffuse, uninformative priors for all model parameters. Models were run with an adaptive phase of 50,000 iterations, followed by 500,000 iterations with the first 250,000 being discarded as a burn-in phase. We ran 4 chains with a thinning rate of 200. Convergence was assessed based on the Gelman-Rubin R-hat statistic and visual inspection of traceplots. Statistical results are only presented for those species in which model convergence was achieved.

Results

We identified 19 species of ducks in Kachemak Bay during winter surveys (Table 2). Ten species or species-groups had sufficient data for analysis, while the remaining species were detected too rarely for formal analyses to be feasible. We present results for those 10 species or species groups, as well as for all sea duck species (as regulatorily defined, not as taxonomically defined) combined and all duck species combined. We occasionally observed Canada geese (*Branta canadensis*) and swans (*Cygnus* spp.) during surveys, but those data are not reported herein. Loons (*Gavia* spp.) and sea otters (*Enhydra lutris*) were also regularly observed during surveys.

Across the 10 survey years we counted a total of 164,596 ducks. Barrow's goldeneye were the most abundant species comprising 18.7% of the total count (Table 2), though the actual number of Barrow's goldeneye observed was likely higher given that approximately 5,000 birds were simply identified to the goldeneye group. Mallards were the second most common species observed, comprising 18.6% of the total count. Other commonly observed species included black scoters, greater scaup, harlequin ducks, surf scoters, and white-winged scoters (Table 2).

Density across species and years tended to be higher along the southeastern shore of Kachemak Bay, with density being particularly high in Halibut Cove, China Poot Bay, and Tutka Bay (Figs. 3 and 4-L). Bufflehead, goldeneye, harlequin ducks, mallards, American green-winged teal, and scaup were encountered far more frequently during shoreline surveys than aerial surveys (Fig. 5). Conversely, white-winged scoters and eiders were most commonly encountered during aerial surveys (Fig. 5). Black scoters, American wigeon, northern pintail, mergansers, long-tailed ducks, and surf scoters were encountered somewhat frequently in both aerial and shoreline surveys (Fig. 5).

Black Scoters

Black scoters were found in the near-shore waters around much of Kachemak Bay (Fig 4-A) and comprised 7.1% of the overall number of ducks observed across all survey years (Table 2). While they were commonly observed during both aerial and shoreline surveys, the majority of observations were made during shoreline surveys (Fig. 5). Model selection results indicated that, of the distributions considered, black scoter counts were best described using a negative binomial distribution (Table 3). Model results show an annual increase of approximately 2.33% in the abundance index for black scoters (Figs. 6–7). This positive trend was estimated with some uncertainty given that the 95% credible interval (CrI) for the rate of change overlapped zero (95% CrI = −0.51–5.21).

BUFFLEHEAD

Bufflehead comprised <4% of the total duck count (Table 2) with virtually all observations (99.3%) occurring during shoreline surveys (Fig. 5), primarily along the southeastern shore (Fig. 4-B). Model selection results suggested that bufflehead counts were best described using an over-dispersed Poisson distribution (Table 3). Model results show an annual increase of approximately 2% in the abundance index for bufflehead (Figs. 6–7); though the 95% credible interval for the rate of change encompassed zero (95% CrI = −0.26–4.34) which indicates some uncertainty in the trajectory.

GOLDENEYE (SPECIES COMBINED)

Goldeneyes were the most abundant species group across all years, comprising 25.1% of the total duck count (Table 2) with 99% of observations occurring during shoreline surveys (Fig. 5). Goldeneye were observed along much of the shoreline, but densities tended to be highest along the southeastern side of Kachemak Bay (Fig. 4-C). Model selection results suggested that goldeneye counts were best described using an over-dispersed Poisson distribution (Table 3). Model results show an annual decrease of approximately 0.74% in the abundance index for goldeneye (Figs. 6–7); though the 95% credible interval for the rate of change encompassed zero (95% CrI = −2.32–0.89) which indicates considerable uncertainty in the trajectory.

HARLEQUIN DUCKS

Harlequin ducks comprised 10.7% of the total duck count (Table 2) with virtually all observations (98.4%) occurring during the shoreline surveys (Fig. 5) and with densities being highest between Sadie Cove and Seldovia Bay (Figs. 3 and 4-D). Model selection results suggested that harlequin duck counts were best described using an over-dispersed Poisson distribution (Table 3). Model results show an annual increase of approximately 1.17% in the abundance index for harlequin ducks (Figs. 6–7); though the 95% credible interval for the rate of change encompassed zero (95% CrI = −0.24–2.61) which indicates some uncertainty in the trajectory.

LONG-TAILED DUCKS

Long-tailed ducks comprised 2.4% of the total duck count (Table 2) with observations occurring during aerial and shoreline surveys (Fig. 5). Unlike most other species, long-tailed duck densities tended to be highest along the northwest shore of Kachemak Bay (Fig. 4-E). Model selection results suggested that long-tailed duck counts were best described using a negative binomial distribution (Table 3). Model results show an annual decrease of approximately 0.37% in the abundance index (Figs. 6–7); though the 95% credible interval for the rate of change encompassed zero (95% CrI = −2.29–1.59) which indicates considerable uncertainty in the trajectory.

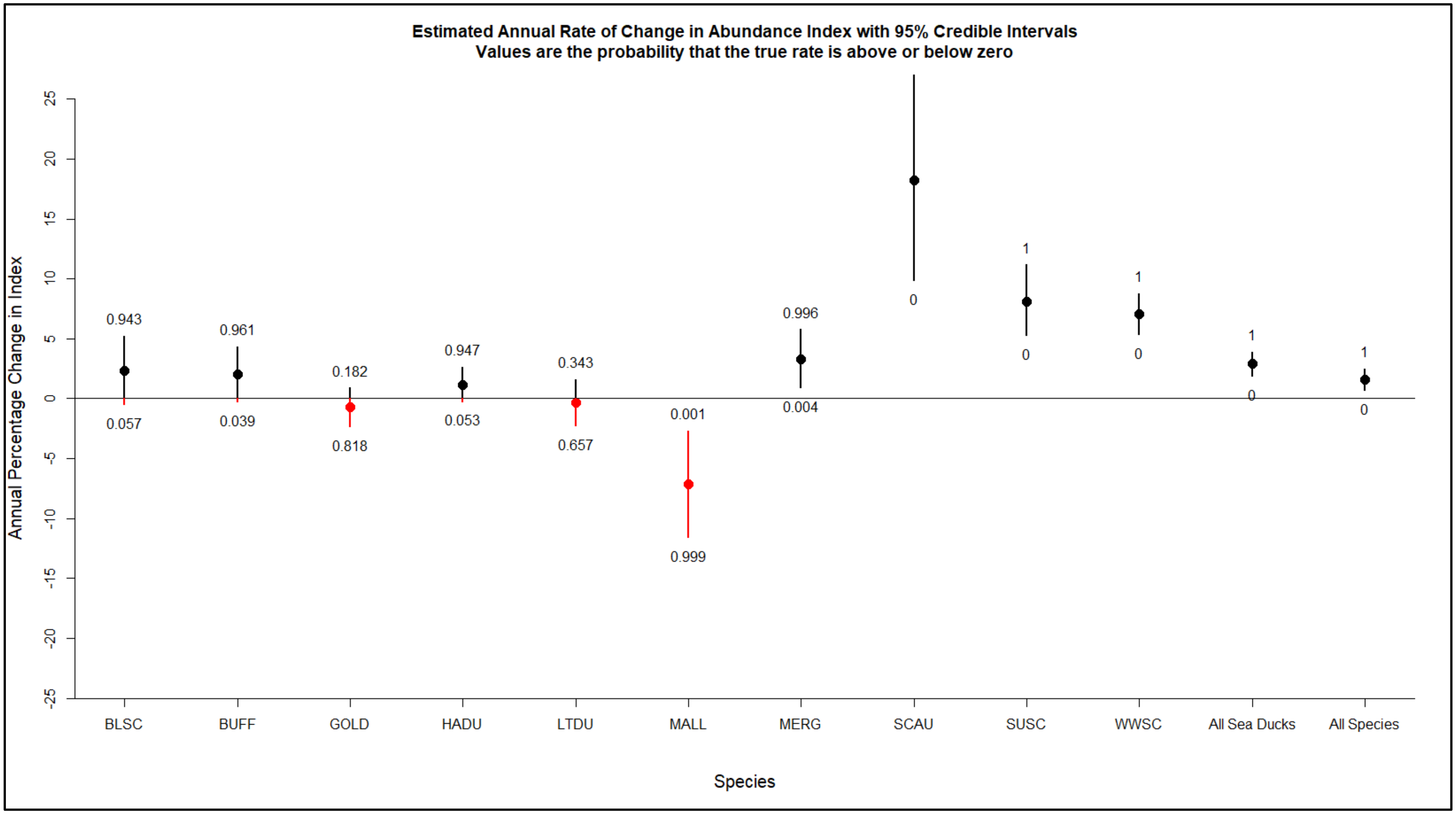

Figure 6. Estimated annual rate of change in the abundance index (with 95% Bayesian credible intervals) for duck species observed during March surveys of Kachemak Bay, Alaska, 1999–2019. Values represent the probability that the true rate of change for a given species is above (top) or below (bottom) zero. See Table 2 for explanation of species alpha codes.

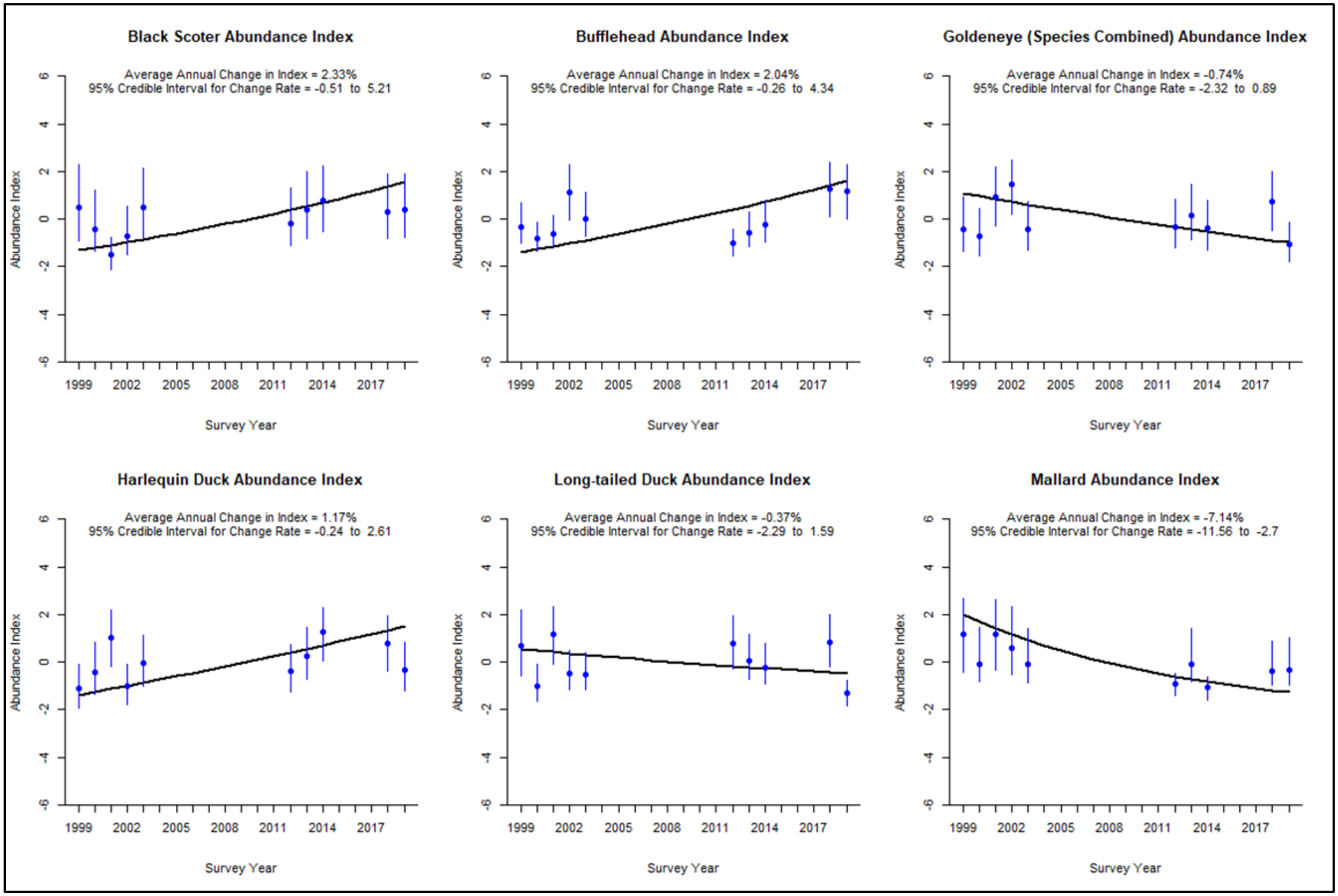

Figure 7. Average annual rate of change in the estimated abundance index for duck species/groups observed during March surveys in Kachemak Bay, Alaska, 1999–2019. Black lines represent the average annual rate of change for the abundance index whereas blue dots and lines represent annual abundance index estimates for years in which surveys were conducted with their associated 95% credible interval, respectively. Positive values for the average annual rate of change suggest that the abundance index is increasing over time. Information presented here is complimentary to Figure 6.

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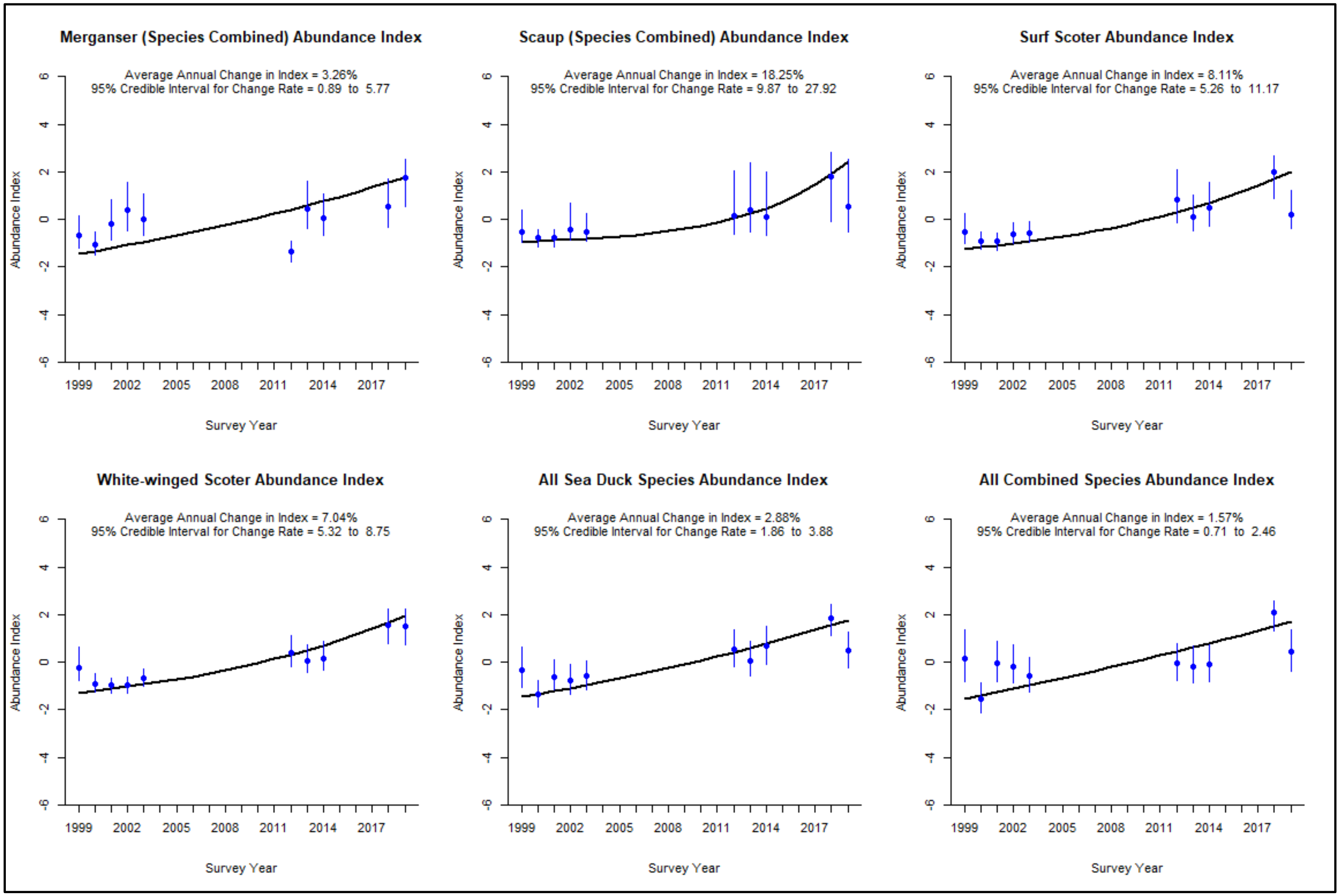

Figure 7 page 2 of 2. Average annual rate of change in the estimated abundance index for duck species/groups observed during March surveys in Kachemak Bay, Alaska, 1999–2019. Black lines represent the average annual rate of change for the abundance index whereas blue dots and lines represent annual abundance index estimates for years in which surveys were conducted with their associated 95% credible interval, respectively. Positive values for the average annual rate of change suggest that the abundance index is increasing over time. Information presented here is complimentary to Figure 6.

MALLARDS

Mallards were the second most abundant species comprising 18.6% of the total count across all years (Table 2). Approximately 98% of observed mallards were found in shoreline segments (Fig. 5). The spatial distribution of mallards tended to be clumped with numbers being highest at the head of Kachemak Bay, near Aurora Bay, China Poot Bay, and Seldovia Bay (Figs. 3 and 4-F). Model selection results suggested that mallard counts were best described using an over-dispersed Poisson distribution (Table 3). Model results show an annual decrease of approximately 7% in the abundance index for mallards (Figs. 6–7). Although the estimated rate of change was not estimated with high precision (as indicated by the broad 95% credible interval), the trajectory was consistently negative (95% CrI = −11.56–−2.70).

MERGANSERS (SPECIES COMBINED)

Mergansers comprised <4% of the total duck count (Table 2) with the majority of observations (79.3%) occurring during the shoreline surveys (Fig. 5). Mergansers were observed along most of the shoreline, but numbers tended to be highest at the head of Kachemak Bay, in Halibut Cove, Sadie Cove, and Tutka Bay (Figs. 3 and 4-G). Model selection results suggested that merganser counts were best described using an over-dispersed Poisson distribution (Table 3). Model results show an annual increase of approximately 3.26% in the abundance index for mergansers (Figs. 6–7) with 95% credible intervals indicating a high probability that the true trajectory was positive (95% CrI = 0.89–5.77).

SCAUP (LESSER AND GREATER SCAUP COMBINED)

Scaups comprised approximately 10% of the total duck count (Table 2) with observations being predominately from shoreline surveys (Fig. 5). Scaups tended to be sporadically distributed along the northwest shore of Kachemak Bay (Fig. 4-H). Model selection results suggested that scaup counts were best described using an over-dispersed Poisson distribution (Table 3). Model results show an annual increase of approximately 18% in the abundance index for scaup (Figs. 6–7) with 95% credible intervals indicating a high probability that the true trajectory was positive (95% CrI = 9.87–27.92).

SURF SCOTERS

Surf scoters comprised 9.5% of the total duck count (Table 2) with observations being fairly common in both aerial and shoreline surveys (Fig. 5). Density of surf scoters tended to be highest along the northwest shoreline between the Homer Spit and the head of Kachemak Bay and in Halibut Cove (Figs. 3 and 4-I). Model selection results suggested that surf scoter counts were best described using a negative binomial distribution (Table 3). Model results show an annual increase of approximately 8% in the abundance index for surf scoters (Figs. 6–7) with 95% credible intervals indicating a high probability that the true trajectory was positive (95% CrI = 5.26–11.17).

White-winged Scoters

White-winged scoters comprised 7.8% of the total duck count (Table 2) with the vast majority of observations (83.6%) occurring during the aerial surveys (Fig. 5). While white-winged scoters were observed throughout much of Kachemak Bay, with the exception of the deepest waters in the middle of Kachemak Bay, numbers tended to be highest near Seldovia Bay, the Homer Spit, and at the mouth of Kachemak Bay (Figs. 3 and 4-J). Model selection results suggested that white-winged scoter counts were best described using a negative binomial distribution (Table 3). Model results show an annual increase of approximately 7% in the abundance index for white-winged scoters (Figs. 6–7) with 95% credible intervals indicating a high probability that the true trajectory was positive (95% CrI = 5.32–8.75).

All Sea Duck Species Combined

As a group, regulatorily defined sea ducks were common throughout most of Kachemak Bay (Fig. 4-K). Model selection results suggested that overall sea duck counts were best described using a negative binomial distribution (Table 3). Model results show an annual increase of approximately 2.88% in the abundance index across all sea duck species (Figs. 6–7) with 95% credible intervals indicating a high probability that the true trajectory was positive (95% CrI = 1.86–3.88).

All Waterfowl Species Combined

Virtually all suitable habitat within Kachemak Bay was utilized by ducks (Fig. 4-L). Model selection results suggested that overall duck counts were best described using a negative binomial distribution (Table 3). Model results show an annual increase of approximately 1.57% in the abundance index across all species (Figs. 6–7) with 95% credible intervals indicating a high probability that the true trajectory was positive (95% CrI = 0.71–2.46).

Discussion

Sea ducks are notoriously difficult to monitor due to their wide-ranging distributions, the remoteness and extreme climatic conditions associated with their coastal habitats, and the varied habitats used by different sea duck species. Consequently, no single survey methodology has been found to be effective for monitoring all sea duck species across management-relevant spatial scales. Even surveys conducted at the same spatial scales frequently employ drastically different survey methodologies with different potential sources of bias and varying degrees of statistical rigor. Thus, it can be difficult, even impossible, to make meaningful comparisons of sea duck abundance estimates through time and/or space. While it can be tempting to treat all survey data equally, it is essential to carefully evaluate field methodologies and consider analytical assumptions before comparing results from different survey efforts. Unfortunately, these realities result in there being few, if any, previous estimates of sea duck abundance or trends for Kachemak Bay that can be meaningfully compared to our estimates.

Data from the federal Harvest Information Program (HIP) suggest that the number of sea duck hunters in Alaska declined by approximately 20% between 2010 and 2020, with the decline being driven by a reduction in the number of Alaska residents who hunt sea ducks. That being said, the number of nonresident sea duck hunters in Alaska has gradually increased over this period (M. Guttery, Division of Wildlife Conservation, ADF&G unpublished data). Although HIP does not provide information regarding where individuals hunt within the state of Alaska, Kachemak Bay is one of the few road-accessible locations in the state that offers public opportunity to hunt a variety of sea duck species in relatively high abundance. Thus, it is likely that Kachemak Bay is among the most popular areas to hunt sea ducks in the state. Residents of the Kachemak Bay area have repeatedly expressed concerns to ADF&G that fall/winter harvest was negatively impacting sea duck abundance in Kachemak Bay. However, results from our analyses suggest that overall abundance of sea ducks (species combined) increased between 1999 and 2019. Similar positive trends in abundance were observed for overall duck numbers (all species combined), as well as for 7 of the 10 individual duck species for which there was sufficient data for analysis.

Three species of ducks did show evidence of decreased abundance over the course of the survey period (mallards, long-tailed ducks, and goldeneye). However, of these 3 species, only the annual percentage change in the mallard abundance index showed strong evidence of a negative trend (95% credible intervals did not overlap 0). A basic regression analysis of estimates from the U.S. Fish and Wildlife Service's Waterfowl Breeding Population and Habitat Survey for the period from 1999–2019 suggests that the mallard breeding population in survey strata 1–12 (Alaska and the Yukon Territory) has declined by approximately 3% per year (Olson 2020). While there is some discrepancy between our estimated decline in the index of mallard abundance in Kachemak Bay in winter and the trend in the breeding population index, there does appear to be evidence that mallards are becoming less abundant in Alaska, including in Kachemak Bay.

According to the U.S. Fish and Wildlife Service (USFWS), the breeding population index for goldeneye (species combined) in Alaska and the Yukon Territory also declined between 1999 and 2019 (mean rate of decline was approximately 6% per year; Olson 2020). Although our findings for Kachemak Bay resulted in some uncertainty about whether goldeneye numbers were, in fact, increasing (18.2% chance) or decreasing (81.8% chance; Fig. 6), there does appear to be good reason to suspect that goldeneye abundance has declined in recent years. Unfortunately, the USFWS Waterfowl Breeding Population and Habitat Survey (WBPHS) does not publish breeding population estimates for long-tailed ducks, the only species of sea duck (as defined by regulations) that appears to be in decline in Kachemak Bay based on our findings.

Due to the lack of effective large-scale monitoring of long-tailed ducks and highly variable results in abundance trends estimated at smaller scales and shorter time periods, the Sea Duck Joint Venture has identified estimation of population size and trend as a high priority data need for long-tailed ducks (https://seaduckjv.org/meet-the-sea-ducks/long-tailed-duck/). While we were able to estimate the trend in the long-tailed duck abundance index for Kachemak Bay with fairly high precision (i.e., narrow range in the 95% credible interval), our estimate resulted in considerable uncertainly in whether the true trend was positive (34.3% chance) or negative (65.7% chance). Long-tailed ducks were one of the more rarely observed duck species in Kachemak Bay (only 2.4% of all ducks detected), thus determining the true abundance trend for this species would likely require a substantial and concentrated survey effort.

Of the remaining 7 species for which we had sufficient data for analysis, only 2 species are monitored during the USFWS WBPHS: scaup (species combined) and mergansers (species combined). We found strong evidence that both of these species groups increased in abundance in Kachemak Bay between 1999 and 2019. According to USFWS data for the same period, the breeding population of scaup in Alaska and the Yukon Territory declined at an average annual rate of approximately 3%, whereas the breeding population of mergansers increased by approximately 1.7% per year (Olson 2020). It is unclear why late winter estimates from Kachemak Bay differ substantially from breeding season estimates for all of Alaska and the Yukon Territory but may be a result of the drastic difference in spatial scale of the 2 surveys.

With the exception of deep (>40 m depth) water, ducks in Kachemak Bay during late winter occupy most available habitat. Distribution varied spatially, as some ducks were more common in near-shore (bufflehead, goldeneye, harlequin ducks, mallards, and mergansers) or offshore habitats (white-winged scoters), and some ducks were common in both (surf and black scoters, long-tailed ducks; Fig. 5). These differences in distribution are undoubtedly related to foraging strategies as well as food preference and availability. Because of this varied spatial distribution, a survey restricted to either shoreline or offshore areas alone would result in biased counts and species composition of ducks in Kachemak Bay.

Summary

Our initial goal was to obtain annual estimates of abundance and describe composition and distribution of ducks inhabiting Kachemak Bay during winter. Unfortunately, estimating abundance proved to be impossible given our survey design. Regardless of this fact, the data reported here represent the only multi-year study of waterfowl in Kachemak Bay and provide an excellent source of baseline data in the event of an environmental perturbation (Klosiewski and Laing 1994).

Kachemak Bay contains a wide range of habitats important to wintering, migrating, and breeding birds (Erikson 1977). The abundance and composition of the marine bird community varies seasonally, with the lowest densities and least diversity occurring during winter (Erikson 1977, Agler et al. 1995). For ducks, however, densities during winter are substantially higher than during summer (Agler et al. 1995). The seasonal importance of Kachemak Bay to ducks may be more critical during the winter when, in some years, it provides a major portion of the total ice-free habitat available in lower Cook Inlet (LCI; Erikson 1977). Ducks may concentrate in Kachemak Bay when ice prevents access to other areas of LCI. It is possible that interannual variation in duck numbers in Kachemak Bay may be related to winter temperatures, and consequently, the overall amount of ice in LCI. While we did not attempt to address this hypothesis in the analyses presented herein, with additional years of survey data it may be possible to evaluate whether this hypothesized relationship indeed exists.

With 10 years of survey data, we are beginning to understand trends in the waterfowl aggregations utilizing Kachemak Bay in late winter. With continued monitoring and refinement of survey methodology, it is possible to improve the accuracy of trend estimates for duck populations at the local level. However, such efforts would be costly in terms of time and money and are of questionable utility given that waterfowl are not typically managed at local levels such as Kachemak Bay.

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