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Trends in Subsistence Harvests of Ice Seals in the Yukon-Kuskokwim Delta Region, Alaska, 1962–2018

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ABSTRACT. Ringed (*Pusa hispida*), bearded (*Erignathus barbatus*), spotted (*Phoca largha*), and ribbon seals (*Histriophoca fasciata*), or ice seals, are harvested for subsistence purposes by many Alaska Native communities. We address trends in the subsistence harvest of ice seals for the Yukon-Kuskokwim Delta region of Alaska for more than 50 years using two types of data collected by the Alaska Department of Fish and Game: (1) bounty data collected from 1962 to 1972 for 16 communities, and (2) household survey data collected for seven of these communities from 1997 to 2018. Both include information on the number of ice seals harvested by each community annually. In addition, more detailed household surveys were conducted from 2008 to 2018 for Hooper Bay, Tununak, and Quinhagak, which collected data on the number of seals harvested by species, the percentage of households engaged in hunting or using seal products, and hunter perceptions. For the bounty period, we identified several years where most communities had above or below average harvests, suggesting regional drivers contributed to patterns in the ice seal harvest. For the seven communities with household survey data, the mean total harvest estimate during the household survey years was only slightly lower than during the bounty period, however, the human population doubled during this time, resulting in a substantial decline in the mean number of seals harvested per person. The more detailed surveys for Hooper Bay, Tununak, and Quinhagak also showed declines in seal harvests during the most recent decade. The declining harvest in some communities may be driven by reduced participation in hunting and less use of seal products. Ongoing sea ice loss is also likely contributing to the decline in harvest across the region. Current seal population estimates indicate all four species are abundant in Alaskan waters, and most hunters have not observed changes in seal abundance.

Key words: ringed seal; bearded seal; spotted seal; ribbon seal; Bering Sea; Yup'ik; household surveys; seal bounty

RÉSUMÉ. Le phoque annelé (*Pusa hispida*), le phoque barbu (*Erignathus barbatus*), le phoque tacheté (*Phoca largha*) et le phoque rubané (*Histriophoca fasciata*), soit les phoques des glaces, sont récoltés à des fins de subsistance par de nombreuses collectivités autochtones de l'Alaska. Nous examinons les tendances en matière de récolte de subsistance des phoques des glaces dans la région du delta Yukon-Kuskokwim de l'Alaska sur une période de plus de 50 ans grâce à deux types de données recueillies par le ministère des Pêches et de la Chasse de l'Alaska : 1) les données de chasse à primes recueillies de 1962 à 1972 pour 16 collectivités, et 2) les données relatives aux enquêtes sur les ménages recueillies pour sept de ces collectivités de 1997 à 2018. Ces deux ensembles comprennent des données sur le nombre de phoques des glaces récoltés par chaque collectivité annuellement. Par ailleurs, des enquêtes plus détaillées sur les ménages ont été réalisées de 2008 à 2018 dans le cas de Hooper Bay, de Tununak et de Quinhagak, ce qui a permis de recueillir des données sur le nombre de phoques récoltés par espèce, sur le nombre de ménages s'adonnant à la chasse ou utilisant des produits dérivés du phoque et sur les perceptions des chasseurs. Pour la période visée par la chasse à primes, nous avons constaté que pendant plusieurs années, la plupart des collectivités avaient enregistré des récoltes au-dessus ou en dessous de la moyenne, ce qui suggère que des facteurs régionaux exerçaient une influence sur les tendances caractérisant les récoltes de phoques des glaces. Dans le cas des sept collectivités visées par les enquêtes sur les ménages, l'estimation moyenne totale des récoltes au cours des années ciblées par les enquêtes n'était que légèrement inférieure aux années de la période de la chasse à primes. Toutefois, durant cette période, la population humaine a doublé, ce qui signifie qu'il y a eu une baisse considérable du nombre moyen de phoques récoltés par personne. Les enquêtes plus détaillées réalisées dans les collectivités de Hooper Bay, de Tununak et de Quinhagak laissaient également entrevoir la diminution des récoltes de phoques au cours de la décennie la plus récente. Dans certaines collectivités, les récoltes à la baisse pourraient être attribuables à la moins grande participation à la chasse et à la moins grande utilisation des produits dérivés du phoque. De plus, la perte continue de glace de mer contribue vraisemblablement à la diminution des récoltes dans l'ensemble de la région. Selon les estimations actuelles de la population de phoques, les quatre espèces sont abondantes dans les eaux de l'Alaska, et la plupart des chasseurs n'ont pas observé de changements sur le plan de l'abondance des phoques.

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Mots clés : phoque annelé; phoque barbu; phoque tacheté; phoque rubané; mer de Béring; Yup'ik, enquêtes sur les ménages; prime pour la destruction de phoques

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INTRODUCTION

Ringed (*Pusa hispida*), bearded (*Erignathus barbatus*), spotted (*Phoca largha*), and ribbon seals (*Histriophoca fasciata*) are collectively referred to as ice seals because of their association with sea ice and their dependence on it for resting, pupping, and molting (Burns, 1970a). All four species of ice seals inhabit the Bering, Chukchi, and Beaufort Seas surrounding western and northern Alaska.

Ice seals are harvested by more than 55 Alaska Native coastal communities and are a primary source of food (Fall, 2018). Seal products are used for making clothes, boat covers, and crafts for local use and commercial sale. Hunting, processing, using, and sharing seals are important parts of Alaska Native culture and heritage (Wolfe, 1981; Fall et al., 2013; Huntington et al., 2017).

The coastal Yup'ik people have harvested ice seals for centuries and continue to do so today (Barker, 1993; Griffin, 2002; Fienup-Riordan et al., 2013). Yup'ik Eskimos primarily populate the Yukon-Kuskokwim Delta (Y-K Delta) of southwestern mainland Alaska. The regional tribal consortium is the Association of Village Council Presidents (AVCP; https://www.avcp.org/), which represents 56 communities, 20 of which are located on or near the Bering Sea coast and regularly harvest ice seals (Fig. 1). Yup'ik hunters from other Y-K Delta communities occasionally travel to the coast to harvest seals or barter and trade for seal meat, oil, and skins (Wolfe, 1981; Fall et al., 2013).

From 1962 to 1972, before passage of the U.S. Marine Mammal Protection Act of 1972 (MMPA), the State of Alaska managed ice seals. During this time, a bounty program encouraged the harvest of harbor seals (*Phoca vitulina*) to reduce predation on commercial fish species, mainly salmonids. However, the bounty program was broadly applied to "hair seals" or phocids, which inadvertently included ice seals in western and northern Alaska, often where little commercial fishing occurred. Hunters were paid $2–$6 for each seal "scalp" (skin from the crown of the head and around the eyes) submitted for bounty. The bounty provided considerable data about ice seal harvest numbers and became more important for monitoring seal harvests than for curbing depredations on fish. During the bounty years, annual harvest data were compiled for most ice seal hunting communities in the Y-K Delta (Fig. 1).

Enactment of the MMPA in 1972 transferred management authority for ice seals (and other marine mammals) from the State of Alaska to the federal government, thus ending Alaska's bounty program. Ice seals are now co-managed by the National Marine Fisheries Service (NMFS) and the Ice Seal Committee (ISC), an

FIG. 1. Coastal communities in the Yukon-Kuskokwim Delta region from which hunters regularly harvest ice seals.

Alaska Native organization consisting of one regional delegate and one hunter representative from each of the five regions in Alaska where ice seal hunting occurs. One member region is the Y-K Delta (AVCP region; https://www.iceseals.org/).

The ISC has identified the collection of annual harvest information as a priority because reporting the numbers and species composition of annual harvests demonstrates their concern for the resource, documents subsistence needs, and is an important component of ice seal management that is required by the MMPA. However, monitoring the harvest of ice seals has been extremely limited. Thousands of ice seals are harvested each year across western and northern coastal Alaska (Nelson et al., 2019); thus, documenting the annual harvest requires long-term dedicated funding and commitment, which has not been provided.

Documenting ice seal harvests is especially important now as northern ocean environments are undergoing rapid environmental change (Huntington et al., 2020). Of significant concern for the Bering Sea is the reduction of sea ice extent and increasing duration of ice-free periods (e.g., Siddon et al., 2020). For ice seals, it is thought that

less sea ice, particularly in the spring when seals use it as a platform for pupping and molting, will negatively affect seal populations (Kovacs et al., 2020; Thometz et al., 2021). All four ice seal species are currently abundant in Alaskan waters (Muto et al., 2020), however, concerns over the impact of projected sea ice loss led to the listing of ringed and bearded seals as threatened under the Endangered Species Act (ESA) in 2012 (U.S. Federal Register, 2012a, b). Decreasing sea ice also affects hunting opportunities, as diminished duration and extent of sea ice have shortened periods when conditions are suitable for hunting and have limited access to seals (Huntington et al., 2016). Changes in hunting opportunity, seal availability near communities, and seal abundance would likely be reflected by trends in the harvest over time.

Our study examined trends in ice seal harvests over the past 50 years. We analyzed data from the bounty program (1962–72), which included 16 of the 20 Y-K Delta coastal communities, and data from recent household surveys (1997–2018), which included seven of those 16 communities. We used regression analyses to identify trends and potential regional patterns in the harvest during the bounty period and compared harvest levels during the bounty period with harvest levels during the household survey period. We also examined more frequently collected and comprehensive household survey data for Hooper Bay, Tununak, and Quinhagak to identify potential drivers of more recent trends in harvest for these three communities. Given the rapid environmental and cultural changes of the past 50 years, it is imperative that efforts to better understand the harvest are made despite limited available data. In doing so, this study clarifies the status of the harvest relative to the past and provides essential information for the effective management of species that are important community resources.

METHODS

Bounty Data

The bounty program produced the first ice seal harvest data in Alaska and included more communities in more years than any subsequent monitoring effort. The information collected was reported as the total number of seals (all species combined) for each year and each community (Burns et al., 1964; Burns, 1965, 1966, 1967, 1968, 1969, 1970b, 1972, 1973). We examined the annual total harvest and per capita harvest (i.e., total harvest divided by total human population) for each community with four or more years of records (n = 16 communities). Bounty data are likely biased low because not all harvested seals were bountied, and seals that were struck and lost (i.e., shot but not retrieved, and likely died) were not reported. Bounty data were sometimes augmented based on information provided by field personnel and local hunters.

Household Survey Data

After the bounty on ice seals ended in 1972, harvest data were obtained via household surveys that were conducted from 1997 to 2018 (Table S1). Household survey data were available for seven of the 16 communities with bounty data: Emmonak (n = 4 y), Scammon Bay (n = 3 y), Hooper Bay (n = 13 y), Tununak (n = 6 y), Tuntutuliak (n = 1 y), Eek (n = 1 y), and Quinhagak (n = 9 y) (Table S1, Fig. 1). Typically, a locally hired member of a community surveyed a predetermined number of households. Survey questions focused on the number of seals harvested by household. The level of detail varied; some surveys recorded only the number of each species per year, while others recorded the number of harvested seals by sex, month of harvest, and general age, and the number that were struck and lost. A household list was used by the surveyor to keep track of which, and how many, households were surveyed. That list was confidential so the reported harvest could not be linked to an individual hunter or specific household. Overall results are reported as community totals.

Because surveys do not include every household in a community, total harvest estimates were determined by dividing the recorded harvest by the proportion of households surveyed. The formula for estimating the annual harvest for a given community is $E = R \div S$, where "E" is the estimated total number of seals harvested in the community, "R" is the reported number of seals harvested, and "S" is the proportion of households surveyed.

More detailed household surveys specific to the ice seal harvest were conducted in Hooper Bay (2008–18, Olnes et al., 2020), Tununak (2008–12, 2016, Nelson et al., 2018b), and Quinhagak (2008, 2010–14, 2016, Nelson et al., 2018a) by the Alaska Department of Fish and Game's Arctic Marine Mammal Program (Table S1). These surveys collected additional information from households, including whether any member of the household hunted ice seals or used seal products within the survey year and their perceptions of each seal species' population status.

Analysis

Available data on ice seal harvest levels for the Y-K Delta region are limited, reducing opportunities for more sophisticated analyses beyond the identification of trends. Analyses of trend focused primarily on two metrics: total harvest and per capita harvest. Total harvest is important because it provides information on whether the number of seals being removed from the population changed over time. Per capita harvest is important because it provides information regarding the level of need or use in a community (i.e., the number of harvested seals available to each individual). The per capita harvest estimate is also important for comparing communities or time periods where the human population size differed. All analyses were performed in R (version 4.1.0, R Core Team, 2021).

We compared four models that explored potential trends in the bounty data: (1) a regional trend in harvest by year, (2) harvest varied by community with no regional trend by year, (3) harvest varied by community with a regional trend by year, and (4) harvest varied by community with a community-specific trend by year. Models were built in a generalized linear model framework using a Poisson distribution and a log link function (R function: glm). We used Akaike's Information Criterion (AIC) to compare the models (Burnham and Anderson, 2002). We then assessed the significance of each parameter in the top model using type-II or type-III analyses of deviance (R package: car, R function: Anova). We also calculated the deviance R-squared ([null deviance − residual deviance]/ null deviance) as a measure of model fit. To identify regional patterns that might not be linear in the bounty data, we looked at the residuals of the top model by harvest year, which would highlight remaining variability after accounting for the possible temporal trend and the mean for each community.

We then compared harvest estimates from bounty data to household survey data for the seven communities where household surveys were conducted (Table S1, Fig 1). Most household surveys estimated the number of seals struck and lost. However, seals that were struck and lost were not included in the bounty data. Therefore, when making comparisons between household survey and bounty data, we did not include struck and lost seals. We used generalized linear mixed-effects models to compare the estimated mean harvest between the two time periods, while also accounting for differences among communities (R package: lme4, R function: glmer). For the mean total harvest, we used a Poisson distribution and a log link function, and community was a random effect. We then ran a similar model that was offset by the log of the human population for each community, allowing us to effectively model differences in the mean per capita harvest (Roback and Legler, 2021). Despite limitations and differences between the bounty and household survey data, comparing harvest data collected during the two periods provided some information about the overall change in the numbers of seals harvested during the last 50 years. Statistically significant differences in mean harvest for these seven communities between the bounty period and more recent household survey period could be an indicator of long-term regional trends in annual harvests.

Data from Hooper Bay, Tununak, and Quinhagak were used to look more closely at trends in harvests at the community level. Evaluation of trends by species was possible because these household surveys included the number of each species harvested. Although ribbon seals are included in the analyses of total harvests discussed above, we did not include data on ribbon seals when analyzing trends by species because they were not commonly harvested by hunters in these communities (~1 ribbon seal per year for each community). We tested for trends in total harvest (species combined), per capita harvest, total harvest of ringed, bearded, and spotted seals (separately), and the percentage of households that included active hunters or used seal products. For all response variables, we used the same modeling approach and compared the same four candidate models as described above for the bounty data. For total harvests, our generalized linear models used a Poisson distribution and a log link function. We also modeled total harvests using a Poisson distribution and a log link function, including the log of the human population as an offset (Roback and Legler, 2021), which effectively modeled per capita harvests. For the percentage of households with active hunters or that use seal products, we used generalized linear models with a binomial distribution and a logit link function. In most survey years, hunters were also asked if they thought seal numbers had changed over time. We summarized this information as the percentage of respondents that reported seal abundance near their community as increasing, remaining stable, decreasing, or unsure.

RESULTS

Bounty Data

Patterns in the total harvest were similar to patterns in the per capita harvest, meaning that communities harvesting the most seals also harvested the most seals relative to the size of the human population (Fig. S1). Four communities averaged per capita harvest rates above 1: Scammon Bay, Hooper Bay, Tununak, and Mekoryuk (Table 1, Fig. S1). Some communities showed little variation in harvests across years (e.g., Emmonak, Alakanuk, Nightmute), whereas harvests in other communities varied substantially (e.g., Scammon Bay, Hooper Bay, Mekoryuk) (Table 1, Fig. S1). Regionally, the mean annual per capita harvest was 1.17 seals per person and the mean annual total harvest was 3326 seals (range: 1400–5450).

The top model for bounty data included intercept and trend terms that varied by community (see full statistical results in Table S2). Harvest declined in some communities (i.e., Chevak, Fig. S2) and increased in others (i.e., Mekoryuk, Fig. S2). Viewing the residuals of the top model shows years with above and below average harvests that appear consistent across communities (Fig. 2). For example, all communities had below average harvests in 1967, 1968, and 1972; most communities were above average in 1969 and 1970 (Fig. 2).

Comparison of Bounty and Household Survey Data

The estimated mean annual harvest for seven communities from household survey data was significantly lower than from bounty data (χ^2 = 212.49, d.f. = 1, $p < 0.001$), but the difference was only ~37 seals (221 seals for the bounty versus 184 seals for the household surveys). Changes between the two time periods varied

TABLE 1. Mean per capita ice seal (ringed, bearded, spotted, and ribbon combined) harvests for coastal communities in the Yukon-Kuskokwim Delta region during the bounty period (1962–72) with sufficient data for at least four years. The minimum and maximum values, the year each occurred, and the years with data for each community are also included. Communities are listed from north to south.

Community	Mean per capita harvest	Minimum per capita harvest (year occurred)	Maximum per capita harvest (year occurred)	Years with data
Emmonak	0.03	0.03 (1969–72)	0.03 (1969–72)	1969–72
Alakanuk	0.22	0.19 (1972)	0.26 (1970–71)	1969–72
Scammon Bay	1.09	0.14 (1968)	1.81 (1970)	1962, 1965–72
Hooper Bay	2.07	1.35 (1968)	3.13 (1970)	1962, 1965–72
Chevak	0.91	0.34 (1967)	1.50 (1965)	1962, 1965–72
Tununak	1.33	0.77 (1962)	1.73 (1969)	1962, 1969–72
Nightmute	0.53	0.39 (1972)	0.67 (1970)	1969–72
Tuntutuliak	0.42	0.06 (1968)	0.66 (1970)	1962, 1968–72
Eek	0.74	0.13 (1967)	1.34 (1970)	1962, 1966–72
Mekoryuk	2.95	0.97 (1962)	4.30 (1965)	1962, 1965–72
Chefornak	0.65	0.05 (1968)	0.86 (1970–71)	1968–72
Kipnuk	0.41	0.01 (1962)	0.60 (1969)	1962, 1969–72
Kwigillingok	0.77	0.27 (1962)	1.35 (1970)	1962, 1969–72
Quinhagak	0.33	0.00 (1962)	0.60 (1970)	1962, 1966–72
Goodnews Bay	0.80	0.46 (1972)	0.97 (1962)	1962, 1969–72
Platinum	0.36	0.00 (1972)	0.64 (1970)	1962, 1969–72

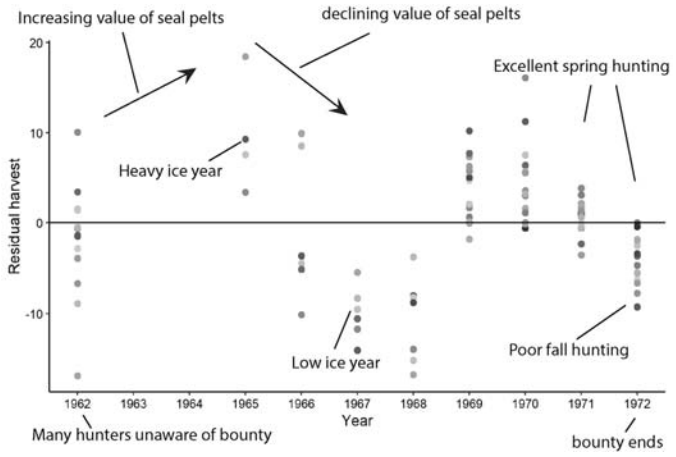

FIG. 2. Residuals of ice seal (ringed, bearded, spotted, and ribbon seals combined) harvests after accounting for village means and temporal trends for the bounty period (1962–72). The regional pattern is apparent for years when most communities had above or below average harvests. Possible reasons for the variability come from Burns et al. (1964) and Burns (1965, 1966, 1967, 1968, 1969, 1970b, 1972).

by community (Fig. 3). Measured as annual per capita harvest, the regional decline in harvest was also significant ($\chi^2 = 5660.2$, d.f. = 1, $p < 0.001$) and more dramatic, dropping from a mean of 0.82 seals per person from the bounty to 0.34 seals per person from household surveys for these seven communities (Fig. 3). None of the seven communities for which household survey data are available had a mean per capita harvest rate above 1.0 seals per person during the household survey period (Table 2). Tununak was the closest at 0.79 seals per person. Per capita harvest of seals that was clearly higher than the bounty period occurred for Emmonak and per capita harvest of seals clearly lower than the bounty period occurred for Hooper Bay (Fig. 3). The human population increased in all seven communities, more than doubling since the bounty (from ~2000 to ~4500 individuals). Communities with more data from household surveys tended to have a greater range in annual total and per capita harvest estimates (Table 2, Fig. 3).

Trends for Hooper Bay, Tununak, and Quinhagak

Household survey data from Hooper Bay, Tununak, and Quinhagak (during the period 2008–18) show statistically significant, negative trends in total and per capita harvests (Fig. 4, Tables S3 and S4). The rate of decline in total harvest (and per capita harvest) was ~45 seals per year (~0.046 seals per person per year) for Hooper Bay, ~16 seals per year (~0.050 seals per person per year) for Tununak, and ~27 seals per year (~0.053 seals per person per year) for Quinhagak. Declines in harvest occurred for all species in all communities (Fig. 4, Tables S5–S7). The decline in harvest was most pronounced for ringed seals at Hooper Bay; a decline of ~28 ringed seals per year. Ringed seals were the primary species harvested at Hooper Bay and Tununak, while at Quinhagak, ringed and spotted seals were harvested at similar levels.

For all species at all three communities, declines occurred in the number of households with active hunters and in households that used seals, though some trends were not statistically significant (Fig. 5, Tables S8–S13). In all years, the percentage of households reporting use of seals was greater than the percentage actively hunting. In most cases, the rate of decline in the percentage of households using seals, however, was greater than the rate of decline in households with active hunters. For example, rates of declining use of ringed seals were ~2%, ~4%, and ~3% of households per year for Hooper Bay, Tununak, and Quinhagak, respectively, but the decline in active ringed seal hunters was not statistically significant for Hooper Bay, and ~2% of households per year at Tununak and Quinhagak.

Perceptions among hunters about changing seal abundance were variable among communities, but

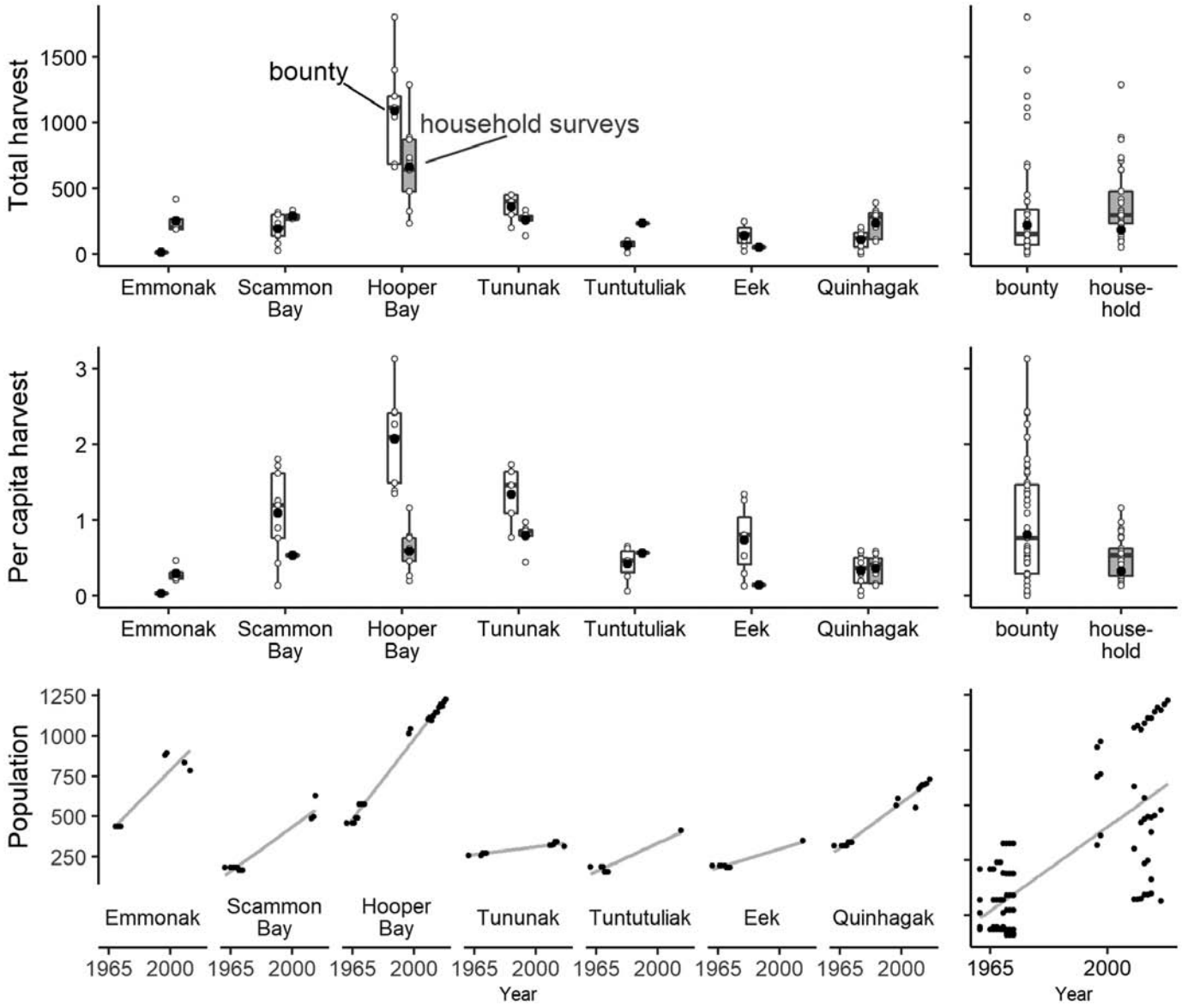

FIG. 3. Mean, median, and ranges of annual total and per capita ice seal (ringed, bearded, spotted, and ribbon combined) harvests for seven Yukon-Kuskokwim Delta communities. Black circles are the mean, gray horizontal lines are the median, and boxes are the interquartile range for each sample. Periods compared are the 1962–72 bounty period (white) and 1997–2018 when household surveys were intermittently conducted (gray). Struck-and-lost seals are not included. Human population trend by community for both periods are presented as gray trendlines (population estimates come from bounty records, sources in Table S1, and the U.S. Census Bureau [data.census.gov]). Also shown are values for both periods when all seven communities are combined.

within communities, perceptions were similar for each species of seal (Fig. 6). At Hooper Bay, in most years, most respondents (> 50%) were unsure if changes in abundance were occurring for ringed, bearded, or spotted seals, and the proportion of respondents who were unsure appears to have increased during the study period. Most other respondents thought each species appeared stable (10%–40%). At Tununak, respondents (> 75%) were unsure or thought ringed and bearded seals were stable, but a higher percentage thought spotted seals were increasing over the survey period (10%–20%, Fig. 6). At Quinhagak, respondents (> 75%) were unsure or thought seal populations were stable in all years.

DISCUSSION

Bounty Data

Our quantitative analysis of bounty data aligned well with qualitative assessments of conditions affecting the harvest described in the state of Alaska's Marine Mammal Reports (Fig. 2, Burns et al., 1964; Burns, 1965, 1966, 1967, 1968, 1969, 1970b, 1972, 1973). Most variability in the bounty data probably came from annual differences in weather and ice conditions. Weather and ice conditions primarily drove patterns of seal harvest because these conditions affect seal movements and hunter access (Burns, 1970). For example, 1967 was a low ice year, and breakup was early and rapid

TABLE 2. Mean per capita ice seal (ringed, bearded, spotted, and ribbon combined) harvests for seven communities with household survey data during the years 1997–2018. The minimum and maximum values, the year each occurred, and the years with data for each community are also included. Communities are listed from north to south. Struck-and-lost seals are not included.

Community	Mean per capita harvest	Minimum per capita harvest (year occurred)	Maximum per capita harvest (year occurred)	Years with data
Emmonak	0.29	0.21 (1998)	0.47 (1997)	1997, 1998, 2008, 2011
Scammon Bay	0.54	0.53 (2013)	0.55 (2011)	2011–13
Hooper Bay	0.59	0.20 (2014)	1.16 (2009)	1997, 1998, 2008–18
Tununak	0.79	0.45 (2016)	0.97 (2011)	2008–12, 2016
Tuntutuliak	0.57	0.57 (2013)	0.57 (2013)	2013
Eek	0.15	0.15 (2013)	0.15 (2013)	2013
Quinhagak	0.36	0.14 (2016)	0.59 (2008)	1997, 1998, 2008, 2010–14, 2016

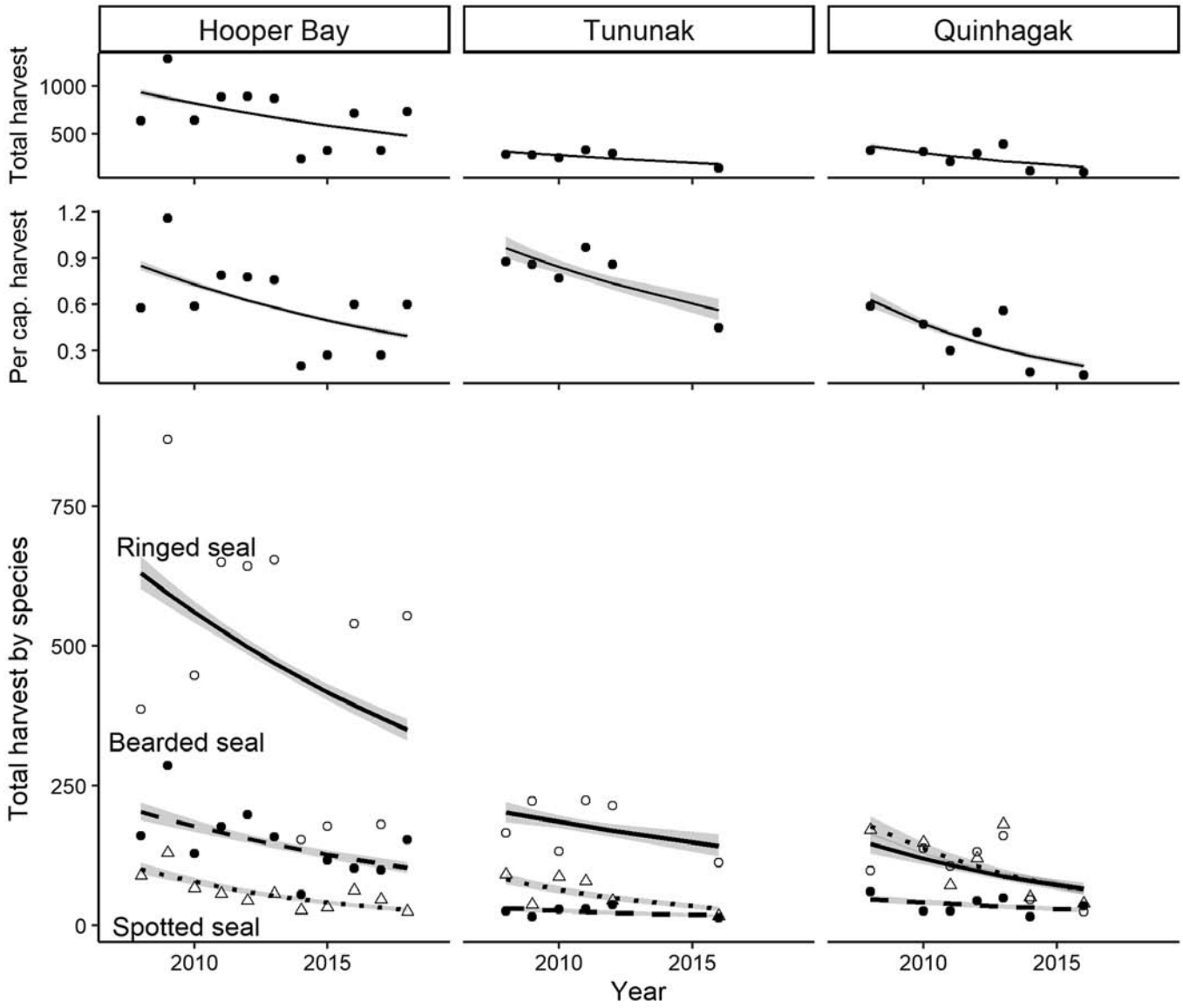

FIG. 4. Total harvests, per capita harvests, and harvests of ringed (open circles), bearded (closed circles), and spotted seals (triangles) in each year from 1998 to 2018 for Hooper Bay, Tununak, and Quinhagak. Lines are fitted trend lines over time (ringed seal: solid line, bearded seal: dashed line, spotted seal: dotted line), and grey bands represent standard error around each fit. All trends are statistically significant ($p < 0.05$).

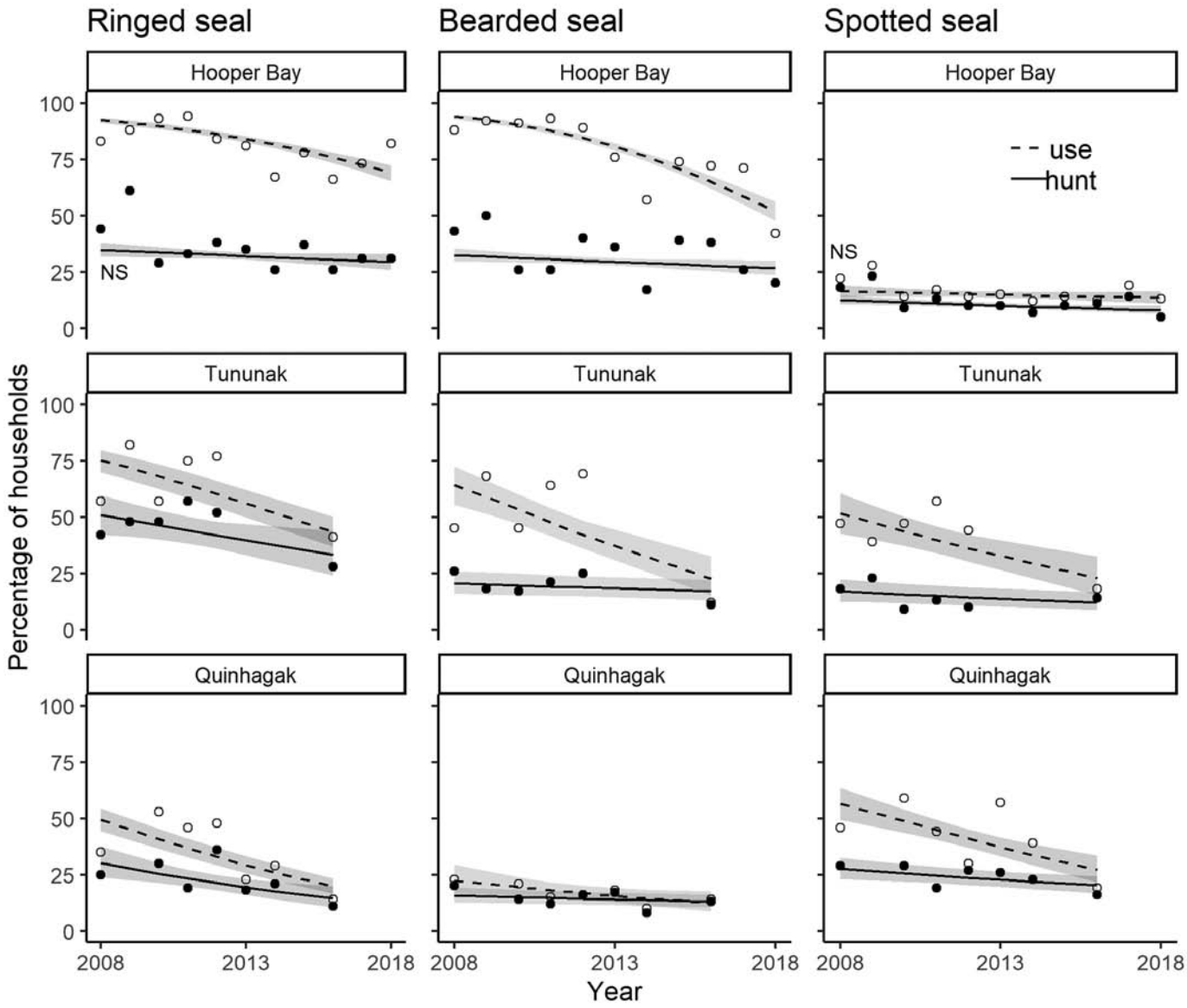

FIG. 5. Percentage of households that reported using (open circles) or hunting (black circles) each seal species each year from 2008 to 2018 based on household surveys at Hooper Bay, Tununak, and Quinhagak. Solid lines are fitted trend lines over time, and grey bands represent standard error around each fit. All trends are statistically significant ($p < 0.05$) except for households that hunt ringed seals and use spotted seals in Hooper Bay where "NS" denotes trends that are not significant.

(Burns, 1968), which limited hunting opportunities in the Y-K Delta. Bounty records reflect lower than average harvests for this year (Fig. 2). Conversely in the springs of 1965 and 1971, the pack ice was extensive, and breakup was prolonged, which increased hunting opportunities by extending the period hunters could be active on the ice (Burns, 1972). Bounty records are higher than average for these years (Fig. 2). Spring hunting conditions were also good in 1972 (persistent and stable ice), but warm weather and storms prevented sea ice formation until December, resulting in poor autumn hunting conditions and a lower overall annual harvest (Burns, 1972). The value of seal skin was likely another regional driver of harvest variability (Burns, 1970). Demand in Europe increased the value of ringed and spotted seal skin in 1962 when ringed seal skin were worth $8 and spotted seal skin were worth $10–$20 (Burns et al., 1964). Prior to 1962, a bearded seal skin had no commercial value, but by 1964, they were worth nearly $25 (Burns, 1965). Demand for seal skin then declined during the second half of the 1960s. The increasing and then decreasing value of seal pelts may have contributed to harvests shifting from above- to below-average harvest levels during this time (Fig. 2). Years with misinformation about the status of the bounty program reduced participation (i.e., 1962, 1968), which biased reported harvest levels downward (Burns et al., 1964; Burns, 1969) and may be why harvests were below average for those years (Fig. 2). Despite caveats, such as varying levels of participation, that require bounty data to be interpreted with caution, these data improve our understanding of the ice seal harvest

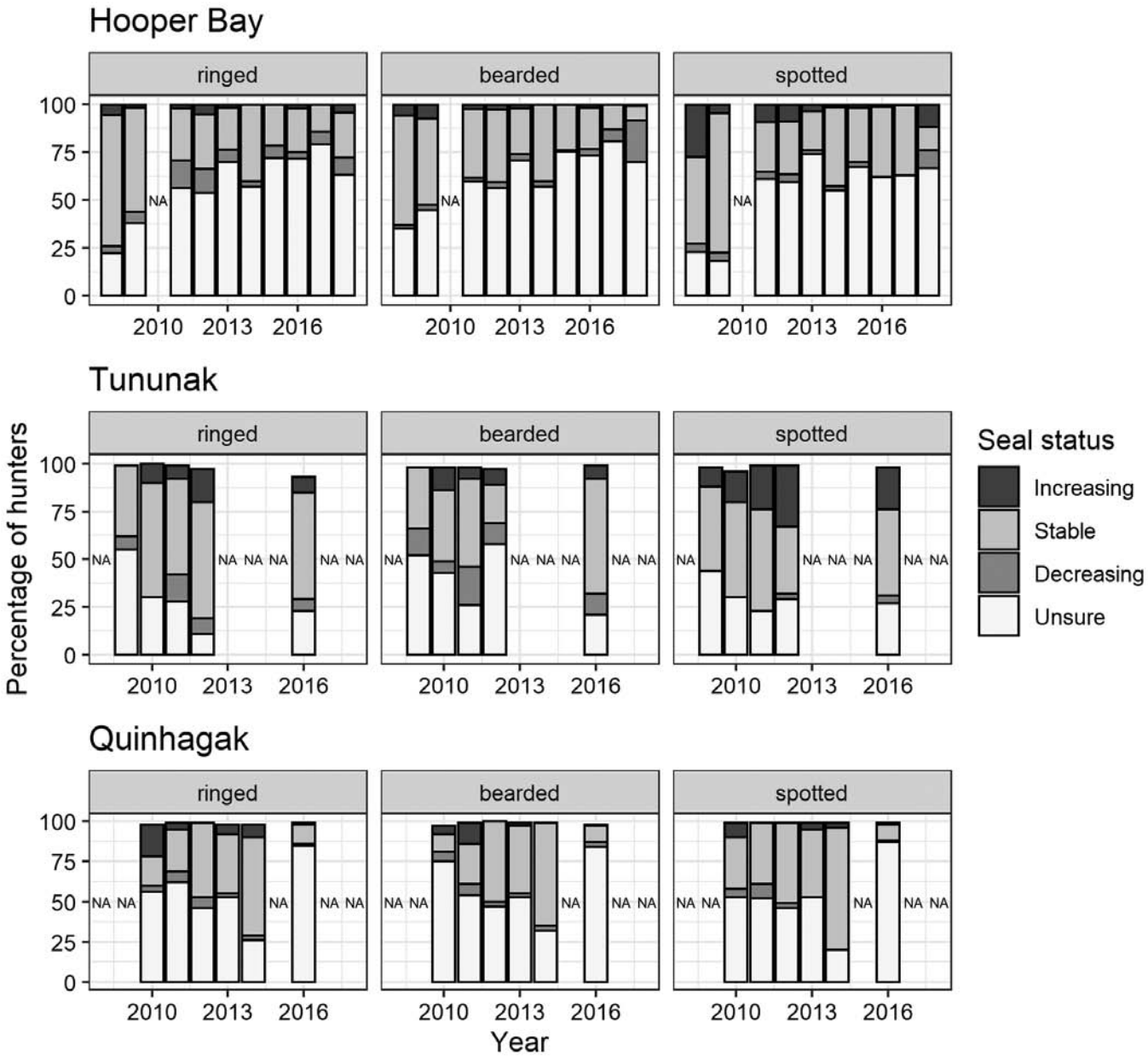

FIG. 6. The percentage of responses from hunters at Hooper Bay, Tununak, and Quinhagak in each year from 2008 to 2018 that reported their perception of seal populations as increasing, remaining stable, decreasing, or unsure.

during these years. The data show that trends during this decade varied by community (both increasing and decreasing harvest levels over time), but regional patterns were also identifiable (Fig. 2). This result is important because the bounty period (1962–72) occurred prior to the substantial decline in sea ice, change in ice seal management (i.e., MMPA), and ongoing cultural changes that affect the harvest today. Thus, our analysis of the bounty data serves as a critical benchmark for comparison.

Household Surveys

There was concern that termination of the seal bounty due to the passage of the MMPA "may have eliminated the possibility of determining the magnitude and characteristics of the annual seal harvests on a routine basis" (Burns, 1973:4). Nearly 50 years later, that assessment appears to be accurate. In the Y-K Delta, only five communities (Emmonak, Scammon Bay, Hooper Bay, Tununak, and Quinhagak) have been surveyed more than once since 1997 (Table S1). The paucity of harvest data from recent years means evaluation of regional patterns or trends is not feasible. Nonetheless, the available data provided some opportunity to assess how recent harvest levels compare to the past. The mean total harvest during recent years was similar to the mean harvest during the bounty years for seven communities. Because the human population doubled between the two periods, we expected total harvests

would have increased proportionally. However, total seal harvest increases were evident for only three of the seven communities (Emmonak, Tuntutuliak, and Quinhagak) (Fig. 3). Despite population growth for these communities, minimal change in the mean total harvest resulted in a large overall decline in mean per capita harvest rate. However, the magnitude and direction of change in per capita harvest varied by community (Fig. 3). For communities where the per capita harvest rate increased over time (Emmonak, Tuntutuliak, and Quinhagak), the difference between the two periods was relatively small (< 0.26 seals per person), whereas for communities where the per capita harvest rate declined (Scammon Bay, Hooper Bay, Tununak, and Eek), the differences were much larger (> 0.54 seals per person), resulting in an overall mean change that was negative. It is also notable that Hooper Bay, the community with the largest human population and the highest total harvests, exhibited a substantial decline in per capita harvests from 2.07 (Table 1) to 0.59 (Table 2). The harvest of ice seals appears to be declining at these four communities despite substantial human population growth.

The reasons harvest estimates did not increase with growing human populations are likely related to cultural and environmental changes during the last 50 years. Replacing sled dogs with snow machines greatly reduced the number of seals required to meet a community's needs (e.g., Burns, 1967; Anderson, 1992, Gryba et al., 2021). The change to snow machines may have also changed hunting patterns with a move to shorter trips reducing opportunities for younger hunters to observe and learn about weather and safe sea ice conditions (Fall et al., 2013; Fienup-Riordan et al., 2013) so that they may be less likely to hunt seals in marginal conditions. Conversely, the shift to more permanent settlements around churches and schools that took place prior to and during the 1960s resulted in hunters traveling farther from home to reach traditional hunting areas (Fienup-Riordan et al., 2013). These changes require more cash to pay for equipment and fuel than in the past when seals fueled dog teams. As a result, cash and subsistence economies are more closely intertwined (Wolfe, 1981; Fall et al., 2013). Although the MMPA allowed for the sustainable harvest of ice seals by Alaska Natives, it also restricted the selling of unaltered seal skins to non-Natives and may have reduced opportunities to generate cash from harvesting seals at a time when more cash was needed to engage in hunting (Frost, 1985). In addition, environmental change has also increased the cost of subsistence activities. Thinner ice and earlier breakup, coupled with frequent stormy weather, have made seal hunting more dangerous. Larger boats and motors are needed to safely hunt when ice is less extensive because hunters must travel farther in rougher water to find seals (Huntington et al., 2016, 2017). Hunters from several Alaska Native communities describe later ice formation in the autumn, thinner ice in the winter, and earlier, faster ice breakup in the spring (Fall et al., 2013, Huntington et al., 2016, 2017). These factors will continue affecting the magnitude of the ice seal harvest regionally, suggesting harvests levels are likely to remain stable or continue trending downward.

Trends for Hooper Bay, Tununak, and Quinhagak

Household survey data from 2008 to 2018 indicated that ice seal harvests declined for Hooper Bay, Tununak, and Quinhagak (Fig. 4). Additional data collected during household surveys indicate that declining harvests may be attributable to less hunting and less use of seal products. In most cases, the number of households with active hunters declined (Fig. 5), and of households that included active seal hunters, there was a decline in hunter effort (Fig. S3). Similar trends were noted for other Bering Sea communities that were surveyed in 2009 (Fall et al., 2013). As another potential example of regional declines in ice seal hunting, the percent of households in Kotlik, Emmonak, Alakanuk, and Nunam Iqua that harvested seals in 1980–81 ranged from 56% to 100% (Wolfe, 1981). Although these are different Y-K Delta communities, these percentages are notably higher than the 16%–61% of households that included active hunters at Hooper Bay, Tununak, and Quinhagak in 2008–18 (Fig. 5). We suspect this difference is a further reflection of fewer households in the region engaging in seal hunting over time. Significant declines also occurred in the proportion of households using seals (Fig. 5). It is common for hunters from a few households to share their catch widely among other households in Alaska Native communities (Wolfe, 1981; Fall et al., 2013). The decline in households that use seal products was greater than the decline in households with active hunters (Fig. 5) suggesting fewer members of the community are using seal products, and these tend to be households that do not include hunters.

Decreasing hunter effort is likely due to a combination of environmental (i.e., less ice), economic (i.e., increasing equipment and fuel costs), and societal changes (i.e., decreasing participation in seal hunting), whereas decreases in use of seal products may be due to economic (i.e., less reliance on subsistence resources) and societal changes (i.e., less demand for subsistence resources). Supplementary comments from survey respondents commonly cited high gas prices, no boat, no time due to work, and family as reasons for hunting less (Alaska Department of Fish and Game, unpubl. data). Some respondents stated that no one in their household is interested in hunting or eating seals. Less hunting opportunity due to environmental conditions could also result in less sharing, though this possibility was not covered during household surveys.

Less hunting is most likely caused by the factors discussed above and not by declining ice seal populations as hunters did not report declining populations in this study (Fig. 6). At Hooper Bay, where harvest estimates were highest, however, the proportion of hunters perceiving seal populations to be stable decreased, while the proportion expressing uncertainty about trends increased. In other studies, hunters reported seals to be abundant but difficult

to access when ice conditions are less reliable and hunting opportunities occur over a shorter period (Huntington et al., 2017). In Bristol Bay, the southernmost ice seal hunting region, observed declines in the local abundance of ice seals were reported by hunters to be related to the decline in sea ice presence (Fall et al., 2013) and not a population decline. Although similar observations have not been reported for the Y-K Delta, this possibility emphasizes the need to document hunter perspectives as the region continues to warm, and sea ice becomes less extensive.

Struck and Lost

Struck and lost seals are an important component of determining subsistence harvest removals. Lack of recovery of shot seals (i.e., struck and lost) is a common occurrence, despite significant efforts by hunters to avoid such losses (Griffin, 2002). Many factors may affect the struck and lost rate, including fewer hunting opportunities resulting in hunters taking riskier shots, fewer seals on ice and more in open water, rifle adequacy and ammunition availability, and hunter experience (Smith, 1981). The species being hunted and the time of year may also influence the likelihood of a seal being lost. Hunters from Utqiaġvik (formerly Barrow) note that spotted seals sink faster than bearded and ringed seals (Gryba et al., 2021). Seals shot in the summer, when they tend to be thinner, are more likely to sink than seals shot in the winter when they have thicker blubber. Given that numerous factors can influence the number of seals struck and lost, estimates of struck and lost rates are highly variable, and few data are available, addressing struck and lost seals is outside the scope of this paper and will require a dedicated study to determine reliable values.

Implications for Management and Future Harvest Monitoring

The threatened ESA listing status of ringed and bearded seals defines their populations as depleted under the MMPA regardless of their actual population numbers. A depleted status removes a step in the process to place limitations on subsistence harvests; therefore, accurate harvest data are needed. The more limited the harvest data, the more conservative managers need to be to protect species and ensure harvests are sustainable. Our findings regarding ice seal harvests in the Y-K Delta alleviate some concerns regarding the magnitude and direction of harvest trajectories. Harvests for the Y-K Delta represent a substantial proportion of total seal harvests in Alaska (~38% of ringed seals, ~20% of bearded seals, ~23% of spotted seals, and ~14% of ribbon seals; Nelson et al., 2019). Despite the geographic, cultural, and economic differences of each seal-harvesting region in Alaska, many harvest patterns identified for this region likely apply elsewhere (i.e., declining sea ice altering access to seals; Huntington et al., 2016, 2017; Gryba et al., 2021; Hauser et al., 2021). However, surveys from more communities in other regions are needed to determine the consistency of these patterns elsewhere. Given that the subsistence harvests of ice seals are currently sustainable (Nelson et al., 2019) and not considered a threat to seal populations, seals remain abundant, and trends in harvest appear stable or declining, it seems that harvest restrictions in the Y-K Delta region are not warranted at this time. However, continued monitoring of the subsistence harvests is needed to detect changes in seal harvest and availability. Documenting the harvest can be accomplished more efficiently by prioritizing surveys in communities that harvest the most seals. In addition, larger communities that have a lower proportion of Alaska Natives need to be surveyed (e.g., Nome, Kotzebue, Utqiaġvik) to evaluate their harvest levels, which could be lower than what might be determined by simple extrapolation.

CONCLUSION

A comparison of seal harvest data from the bounty years (1962–72) to household survey data (2008–18) showed that seal harvests declined in the Y-K Delta although the human population doubled. In the 2000s, three representative communities documented a decline in harvest for all seal species and for both the proportion of households hunting seals and households using seal products. Reasons for the decline likely include environmental factors such as changing sea ice and weather conditions, which decreased hunting opportunity and made hunting more dangerous (Huntington et al., 2016, 2017), in addition to economic and societal factors such as increased employment opportunity and less use of seal products in the surveyed communities. The harvest decline is apparently not due to decreases in ice seal population sizes according to hunters and current abundance estimates (Muto et al., 2020). Continued harvest monitoring would provide an important indicator of potential changes in local seal availability that could otherwise be missed or misunderstood. Ongoing and better documentation of the harvest and struck and lost rate is also important for monitoring how environmental and anthropogenic changes will affect harvests and use of ice seals in the future. Focusing efforts on communities that harvest the most seals regionally will allow future harvest monitoring to be accomplished more efficiently.

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