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Subsistence harvest of ringed, bearded, spotted, and ribbon seals in Alaska is sustainable

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ABSTRACT: In 2012, climate-warming related decreases in sea ice led to listings of ringed *Pusa hispida* and bearded seals *Erignathus barbatus* as threatened under the United States Endangered Species Act (ESA) prior to evidence of population declines. These and 2 other ice-associated species (spotted *Phoca largha* and ribbon seals *Histriophoca fasciata*) are vital subsistence resources to coastal Alaska Native communities. ESA-related assessments concluded that subsistence removals (seals that were harvested as well as those that were struck and lost) were sustainable; however, limited data precluded a quantitative evaluation. Potential biological removal (PBR), defined as the maximum number of animals that can be removed from a stock while allowing the stock to reach or maintain its optimal sustainable size, is typically used to determine whether human-caused mortality is sustainable. Although developed to address commercial fisheries bycatch, PBR serves as a conservative measure of sustainability. We compiled annual subsistence removal of ice seals in Alaska between 1992 and 2014 for 41 of 55 ice seal hunting communities and used per capita (based on the 2015 human population) removal estimates from surveyed communities to estimate regional and statewide average removals. We used average per capita values of harvest, combined with struck and lost, for surveyed communities (average removals) to extrapolate to unsurveyed communities. To account for underreported harvest, we also extrapolated using maximum harvest values, providing a liberal estimate. Both the average and liberal estimates of removals were below PBR for all 4 species. Thus, the best available data indicate that subsistence hunting is currently sustainable for all 4 species of ice seals.

KEY WORDS: *Erignathus barbatus* · *Pusa hispida* · *Phoca hispida* · *Phoca largha* · *Histriophoca fasciata* · Ice seal · Potential biological removal · Struck and lost

1. INTRODUCTION

Ringed *Pusa* (also *Phoca*) *hispida*, bearded *Erignathus barbatus*, spotted *Phoca largha*, and ribbon *Histriophoca fasciata* seals, collectively called 'ice seals', inhabit the Bering, Chukchi, and Beaufort seas of Alaska, USA. Ice seals are vital resources to subsistence-dependent coastal Alaska Native communities (Fall 2014). They are primarily hunted by 55 communities within 5 geographic regions delineated by regional native governments and corporations: North Slope (North Slope Borough, NSB), Northwest Arctic (Maniilaq), Bering Strait (Kawerak), Yukon-Kuskokwim Delta (Association of Village Council Presidents, AVCP), and Bristol Bay (Bristol Bay Native Association, BBNA) (see Fig. 1). Ringed, bearded, and spotted seals are widely used for food, and their skins are used for clothes, boat skins, and handicrafts. Ribbon seals are less common and less preferred for food, but their skins are used for clothing and handicrafts. All marine mammals in the United States are protected under the US Marine Mammal Protection Act (MMPA) of 1972, as amended, but their importance to coastal Alaska Natives for subsistence purposes is recognized by an exemption under Section 101(b) for a legal harvest by Alaska Natives (www.fws.gov/ecological-

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services/es-library/pdfs/mmpa.pdf). Marine mammals are managed by stock, which is defined in the MMPA (Section 3 (11)) as '… a group of marine mammals of the same species or smaller taxa in a common spatial arrangement, that interbreed when mature.' There is no evidence to suggest stock structure exists within any of the ice seal species in Alaska, so for the purpose of determining the sustainability of subsistence harvests in Alaska, we treated each species as a single stock in Alaskan waters (Boveng et al. 2009, 2013, Cameron et al. 2010, Kelly et al. 2010). Understanding the annual subsistence removal (harvest as well as struck and lost) is a basic management necessity and important to ensure that the number of seals used for subsistence and cultural activities does not exceed what is sustainable.

Ice seals are co-managed by the National Marine Fisheries Service (NMFS) and the Ice Seal Committee (ISC) through an agreement signed in 2006 (ISC & NMFS 2006), which was authorized under Section 119 of the MMPA. The fundamental obligation of co-management is 'to conserve marine mammals and provide co-management of subsistence use by Alaska Natives' (MMPA Section 119, Marine Mammal Commission 2007). NMFS is mandated to (1) maintain and recover marine mammal populations to their optimum sustainable population size, (2) maintain populations as a significant functioning element in the ecosystem, and (3) maintain population levels that will allow sustainable subsistence harvests by Alaska Natives (ISC & NMFS 2006). The ISC represents Alaska Natives, who have local and traditional knowledge of ice seals and are dedicated to the long-term sustainable harvest of ice seals for food, culture, and handicrafts (ISC & NMFS 2006). The co-management agreement provides for 'full and equal participation by both Parties [NMFS and ISC] in decisions affecting the subsistence management of marine mammals, to the maximum extent allowed by law' (ISC & NMFS 2006).

In 2012, ringed and bearded seals in Alaska were designated as threatened under the US Endangered Species Act (ESA) because predicted changes in sea ice modeled over the next century would cause them to decline (NOAA 2012a,b). At the time of listing there was no evidence that either species had declined or was declining, and subsistence removals were specifically identified as not a factor in the reasons to list. Species listed as threatened under the ESA are defined as 'depleted' and 'strategic' under the MMPA, which results in higher scrutiny during stock assessments. Few ice seals are killed by commercial fishing (i.e. bycatch) or are known to die by ship strikes (Muto et al. 2018). Although ice seals may be affected by pollution, contaminants, and competition for prey with fisheries, these factors are largely unquantified. The largest known source of human-caused mortality for ice seals is removals by Alaska Natives for subsistence. Here, we refer to 'harvested' seals as hunted seals that are successfully retrieved and 'struck and lost' seals as those that are killed during hunting but not successfully retrieved. Hence, 'subsistence removals' are the total number of both harvested and struck and lost seals. Subsistence hunting is protected under the MMPA and cannot be regulated unless the hunted species is declared depleted under the MMPA or listed under the ESA. Once depleted, however, harvest regulations could be promulgated pursuant to MMPA Section 101(b). Currently, harvest is unregulated for all 4 species of ice seals because harvest is considered sustainable (Boveng et al. 2009, 2013, NOAA 2012a,b) even though it has never been quantified. The threatened and depleted status of ringed and bearded seals heightens the need to document the magnitude and sustainability of subsistence hunting. Harvesting ice seals sustainably will protect the populations and the harvest for the people who depend upon them.

Potential biological removal (PBR) is defined in the MMPA as '…the maximum number of animals, not including natural mortalities, that may be removed from a marine mammal stock while allowing that stock to reach or maintain its optimum sustainable population.' Human-caused removals from a stock are considered sustainable when they are less than PBR (Barlow et al. 1995, Wade & Angliss 1997, NMFS 2005, Moore & Merrick 2011). Stock assessments are required to estimate PBR and human-caused mortality (see MMPA Section 117). Although PBR was originally proposed and is integral for managing the take of marine mammals by commercial fishing operations (see MMPA Section 118, Wade 1998), it is not prescribed for regulation of subsistence harvests. However, it can serve as a conservative measure of sustainability, and as such, may be used as a protective guideline for evaluating stocks for which subsistence harvest is the primary source of human-caused mortality.

In Alaska, subsistence harvest of ice seals has been quantified using household surveys. These surveys have been conducted by private and government entities; some surveys provided numbers of seals struck and lost. These data have never been synthesized to evaluate whether subsistence removals are sustainable. The purpose of the present paper was to

(1) compile ice seal harvest survey data collected in Alaskan communities during 1992–2014, including information on the proportion struck and lost; (2) use the surveys to calculate an annual regional and statewide estimate of ice seal harvest plus struck and lost; and (3) calculate PBR for each species of ice seal and assess the sustainability of subsistence hunting.

2. MATERIALS AND METHODS

2.1. Estimating harvest within communities

Household surveys designed to document how many seals were harvested (and sometimes, struck and lost) were conducted by many government entities (NMFS, State of Alaska, NSB, Maniilaq, Kawerak, AVCP, and BBNA), Alaska Native Organizations (ISC and Alaska Native Harbor Seal Commission), and private contractors (Braund and Associates). Questionnaires used during household surveys differed slightly by surveying entity. However, all surveys were designed to estimate community-level harvest and included questions on how many seals were harvested over a 12 mo period, usually a calendar year. Surveys collected information about all 4 ice seal species in each sampled community, except for some surveys in the Bristol Bay region (Wolfe & Mishler 1993, 1994, 1995, 1996, 1997, 1998, Wolfe & Hutchinson-Scarbrough 1999, Wolfe 2001, Wolfe et al. 2002, 2003, 2004, 2005, 2006, 2008, 2009a,b), which only collected information on spotted seals. Data from surveys are available in a published scientific paper (Fall et al. 2013), a report (ISC 2017) on the ISC's website (www.north-slope.org/departments/wildlife-management/co-management-organizations/ice-seal-committee), and in a searchable online database maintained by the Division of Subsistence of the Alaska Department of Fish and Game, named the 'Community Subsistence Information System' (www.adfg.alaska.gov/sb/CSIS/).

The sample of households surveyed within each community was used to estimate the community-level harvest for each species. Community-level harvest was estimated differently for small and large communities. Almost all sampled communities were small (84 % had <175 households) with an average of 4.3 people household^{-1}. A census was attempted in all small communities surveyed. The level of harvest of sampled households was assumed to be representative of households not sampled. Extrapolation was done by estimating the average harvest per household and then multiplying by the number of households (e.g. Wolfe & Mishler 1993, Ahmasuk & Trigg 2007, Bacon et al. 2009, ISC 2017). In the 3 large (>1400 Alaska Natives) communities of Utqiaġvik (formerly Barrow), Kotzebue, and Dillingham, sampling was stratified by households with low and high levels of harvest. Nome, the only other large community, has never been surveyed. Data were extrapolated to households not surveyed within each stratum, and then strata were summed to determine the community total (Wolfe & Mishler 1993, Whiting 2006).

2.2. Accounting for struck and lost seals

To estimate the total number of seals removed, we had to account for seals that were struck and lost. Little is known about the survival of wounded seals; however, there is some evidence that survival is low for wounded Pacific walruses *Odobenus rosmarus divergens* (Fay et al. 1994). We assumed that wounded seals had lower survival and, when estimating removals, considered a seal struck by a bullet to have died.

Some community surveys included the number of struck and lost seals as reported by the hunters in addition to the number harvested (i.e. retrieved). When struck and lost data were available for a community, we added the number struck and lost to the number of seals harvested to estimate the number of removals. For communities that did not collect information on the number of seals struck and lost, we applied a correction that was estimated using the regional proportion of seals struck and lost. The regional proportion was calculated as the total number of seals struck and lost (pooled across years) divided by the total number of seals removed (harvest plus struck and lost; also pooled across years). Struck and lost information was not collected during any NSB survey; therefore, data from the nearest 2 regions (Maniilaq and Kawerak) were pooled to estimate the proportion of struck and lost for the NSB. Two adjacent regions, instead of one, were used to obtain reasonable sample sizes. In other regions, regional struck and lost proportions were applied to the harvests reported for surveys without struck and lost data to obtain estimates of removal. Thus, harvest data from all surveys used to estimate harvest were adjusted for seals that were struck and lost. We calculated statewide struck and lost proportions as the average of the regional proportions weighted by the number of seals removed by each region. We did not include the derived proportions for the NSB in the statewide proportions presented; however, we did calculate them with and without the NSB estimate and there was little difference (0.002).

2.3. Statewide estimates of subsistence removal

To estimate the statewide subsistence removal (harvest plus struck and lost) of ice seals, we first calculated the per capita rate of removal from sampled communities, as follows:

$$\text{Per capita removals} = \frac{\text{Total no. seals removed year } x}{\text{\# Alaska Natives in community year } x} \quad (1)$$

For each species in a surveyed community, average removal for 2015 was calculated as the mean per capita removal for all surveys in that community multiplied by the Alaska Native population (all ages) living in that community during 2015 as recorded by the US Census (https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml). To estimate removal in 2015 for unsurveyed communities, we averaged the mean per capita values for surveyed communities within that region and multiplied this average by each community's population in 2015. We then added the removals for all communities within a region to obtain the regional estimate of average annual removal by species. Following the same procedure for average removal estimates, but to account for underreported harvest as well as uncertainties due to survey error and extrapolations to communities not surveyed, we also developed a worst-case scenario by using maximum harvest values reported during any year for which data were available; we call this the 'liberal' subsistence removal estimate.

2.4. Trends in struck and lost and removal estimates

We analyzed both struck and lost and removal data for trends and temporal patterns to determine if averaging struck and lost and per capita removal data across years was appropriate, and to see if there had been any significant changes in removal through the survey period (R Development Core Team 2018). We plotted each type of data against survey year and visually examined the data for patterns. We used generalized linear models (function 'glm') with binomial error structure and the logit link to analyze struck and lost proportions for statistically significant trends ($p < 0.05$) at the regional level (by pooling data across communities) and at the community level for communities with >3 surveys with struck and lost data. For removal (count) data, we used generalized linear models with quasi-Poisson error structure and the log link to perform trend analysis for communities with >3 surveys. For regions with sufficient data (i.e. BBNA spotted seal data and NSB bearded and ringed seal data) we assessed trends in removal at both the regional level and the community level using generalized linear mixed models (R package 'lme4', Bates et al. 2015; function 'glmer') with Poisson error structure and the log link. To analyze for trends in removal per capita data (continuous positive values), we used generalized linear models with gamma error structure and the inverse link.

2.5. Quality control of subsistence data

Methods to maximize the accuracy of community surveys included (1) surveying a reasonable number of households from each community (usually >30% of all households), (2) documenting details of how extrapolations and other calculations were made, (3) community outreach regarding the importance of accurate harvest reporting and how results would be used, (4) maintaining household confidentiality (results are only shared as community totals never by individual household), and (5) keeping surveys voluntary (households can decline to participate in the survey without consequences).

The effort and success of subsistence hunters can fluctuate greatly from year to year due to weather, ice conditions, availability of ice seals, employment, and gas prices. Therefore, communities were surveyed in consecutive years, when possible, to address the variability in subsistence removal, document its causes, and detect trends. Conducting surveys in the same communities in consecutive years also added efficiency by having trained surveyors in place and a community familiar with the process to facilitate survey approval.

2.6. PBR and sustainability of harvest

PBR was calculated for each species as:

$$\text{PBR} = N_{\text{min}} \times 0.5 R_{\text{max}} \times F_{\text{r}} \quad (2)$$

where N_{min} is the minimum population estimate, R_{max} is the the maximum rate of population increase, and F_{r} is a recovery factor to further allow for population growth when the population is declining or unknown.

N_{min} is an estimate of the number of animals in a stock that accounts for the uncertainty in population estimates and provides a reasonable assurance that stock size is equal to or greater than N_{min}. N_{min} is calculated as the 20th percentile of a log-normal distribution based on an estimate of the number of animals in a stock (see Wade 1998 and NMFS 2016 for more information). When reliable estimates of abundance that include estimates of uncertainty are not available, as is the case for ice seals, other approaches may be used as the estimate of N_{min}, as long as they provide the same level of assurance that the stock size is equal to or greater than that estimate. Estimates of N_{min} for all seal species were derived from aerial survey data (Muto et al. 2018).

Values for R_{max} and F_r have been chosen to lower PBR when population growth rates or status are not known (as for ice seals). An R_{max} of 12% was recommended as a default for pinnipeds by Wade (1998) and has been used for calculating PBR in stock assessment reports for ice seals (Barlow et al. 1995, NMFS 2005, Moore & Merrick 2011). F_r is added to further protect population growth when deemed necessary. The default value for F_r can be as low as 0.1 (e.g. for endangered species) and as high as 1, when a population is at optimum level or when a population is not known to be decreasing and whose removal is primarily subsistence removal 'provided there have not been recent increases in the level of takes' (NMFS 2016). For populations of unknown population status (i.e. not known if declining, stable, or increasing), such as ringed, bearded, and spotted seals, F_r has been set at 0.5 to lower PBR, thus allowing for additional population growth (Barlow et al. 1995, Moore & Merrick 2011). Recently, however, F_r for ribbon seals was set at 1.0, invoking the 'subsistence' provision described above because of no known population decline and consistent levels of subsistence harvest (Muto et al. 2018). We assessed the sustainability of the subsistence harvest of each seal species by comparing the statewide average and liberal removal estimates to PBR using the accepted default values for R_{max} and F_r.

2.7. Abundance estimates

We used estimates of N_{min} provided by Muto et al. (2018) for spotted (423 247) and ribbon (163 086) seals from aerial surveys conducted in the Bering Sea in 2012 and 2013 that included most of their breeding range and were corrected for availability (Conn et al. 2014). For ringed seals, we combined the results of aerial surveys performed in 2 portions of their range to obtain an estimate of N_{min} of 470 000 ringed seals for the US portion of the Bering, Chukchi, and Beaufort seas (see Table 7). Ringed seals were estimated to exceed 300 000 for US portions of the Chukchi and Beaufort seas (Kelly et al. 2010, Muto et al. 2018). This value is considered a substantial underestimate due to the limited survey area and is therefore an appropriate N_{min} for that area. Similarly, ringed seals were estimated to exceed 170 000 for the US portion of the Bering Sea, and this value is also considered a substantial underestimate because it did not account for availability bias or for seals on shorefast ice (Conn et al. 2014, Muto et al. 2018). For bearded seals, we combined the N_{min} estimated for the US Bering Sea (273 676 seals corrected for availability bias; Conn et al. 2014, Muto et al. 2018) with an N_{min} we estimated from surveys conducted in the eastern Chukchi Sea in 1999 and 2000 (Bengtson et al. 2005). Bengtson et al. (2005) did not adjust bearded seal density estimates from aerial surveys for availability and, citing Krafft et al. (2000), noted that the correction factor could be as high as 12.5. Krafft et al. (2000) presented haul-out data from 4 lactating bearded seals near Svalbard collected during May, approximately the same time of year the surveys were performed. Upon review of these haul-out data, we noticed that the percent of time out of the water during the survey hours (07:30–15:30 h) was greater than the daily average. Therefore, we calculated a survey-window-specific correction factor of 8.3 and applied it to the survey estimates, which yielded a mean abundance of 113 597 seals and an N_{min} of 83 652 bearded seals (i.e. the average of N_{min} = 44 566 in 1999 and N_{min} = 122 738 in 2000). Thus, for bearded seals we combined the estimate of N_{min} for the Bering Sea (273 676 seals) with our estimate of N_{min} for the Chukchi Sea (83 652 seals) for an overall N_{min} of 357 328. Note that our estimate of N_{min} does not include the Beaufort Sea where bearded seals also occur and breed.

3. RESULTS

3.1. Community surveys

The 7 coastal NSB communities were surveyed 2–7 times per community (Table 1). Most surveys were conducted by the NSB, Department of Wildlife Management. The 5 Maniilaq communities were surveyed 2–5 times (Table 2). Fifteen (of 17) Kawerak communities were surveyed 1–4 times (Table 3). Nome, the largest Kawerak community (with 28% of

Table 1. Annual average and liberal subsistence removal estimates (harvest plus struck and lost) of ice seals for the 7 coastal communities in the North Slope Borough region based on household surveys conducted from 1992–2014. No surveys in the North Slope Borough region included struck and lost data; therefore this was estimated using the average estimate of the 2 adjacent regions (Maniilaq and Kawerak)

Community	No. of surveys (no. with struck and lost)	Alaska Native population 2015	Ringed seals		Bearded seals		Spotted seals		Ribbon seals	
			Average[a]	Liberal[b]	Average	Liberal	Average	Liberal	Average	Liberal
Atqasuk[c]	2 (0)	240	3	7	5	7	0	0	0	0
Utqiaġvik (Barrow)[c–e]	7 (0)	2760	465	666	713	1318	39	120	0	0
Kaktovik[c,d,f]	4 (0)	244	19	42	18	23	6	11	0	0
Nuiqsut[c–e]	6 (0)	416	74	185	13	29	3	8	0	0
Point Hope[c,d,g]	4 (0)	701	472	1208	112	191	15	55	0	0
Point Lay[c,g]	3 (0)	285	33	57	48	63	14	29	0	0
Wainwright[c,d,f]	3 (0)	580	80	179	122	189	12	22	0	0
Total	29 (0)	5226	1146	2343	1031	1820	89	245	0	0

[a]Average annual subsistence removal estimated from all available surveys for each community (applies to all 4 species); [b]Liberal annual subsistence removal estimated from the highest estimate from all available surveys for that community (applies to all 4 species); [c]Bacon et al. (2009); [d]Fuller & George (1997); [e]Brown et al. (2016); [f]Burnsilver et al. (2016); [g]Braem et al. (2017)

Table 2. Annual average and liberal subsistence removal estimates (harvest plus struck and lost) of ice seals for 5 communities in the Maniilaq region based on household surveys conducted from 1992–2014

Community	No. of surveys (no. with struck and lost)	Alaska Native population 2015	Ringed seals		Bearded seals		Spotted seals		Ribbon seals	
			Average[a]	Liberal[b]	Average	Liberal	Average	Liberal	Average	Liberal
Buckland[c,d]	2 (1)	432	42	58	89	130	95	104	2	5
Deering[d–f]	3 (1)	127	5	8	49	64	12	25	0	0
Kivalina[d,g,h]	3 (1)	388	80	147	187	251	22	41	4	11
Kotzebue[f,g,i]	5 (0)	2435	363	1217	659	1285	369	637	1	4
Noatak[d,h,j]	3 (1)	443	2	6	52	56	8	22	0	1
Total	16 (4)	3825	493	1436	1038	1786	507	829	9	20

[a]Average annual subsistence removal estimated from all available surveys for each community; [b]Liberal annual subsistence removal estimated from the highest estimate from all available surveys for that community; [c]Magdanz et al. (2011); [d]Shiedt (2012); [e]Magdanz et al. (2002); [f]Braem et al. (2017); [g]Fall & Utermohle (1995); [h]Magdanz et al. (2010); [i]Whiting (2006); [j]Magdanz & Alexander (1995)

the region's population), was not surveyed. Solomon, the only other Kawerak community not surveyed, had a population of 4. Eight (of 20) AVCP communities were surveyed 1–9 times (Table 4). These 8 communities accounted for 49% of the population in the AVCP region and had population sizes fairly representative of the region's other communities. All 6 communities within the northern BBNA region were surveyed at least once for all 4 ice seals, and Togiak and Twin Hills (locations 54 and 55 in Fig. 1) were surveyed 6 and 5 times, respectively (Table 5). All BBNA communities were surveyed for spotted seals during a long-term (15–20 yr) harbor seal and sea lion survey conducted jointly by the Alaska Department of Fish and Game and the Alaska Native Harbor Seal Commission (Wolfe & Mishler 1993, 1994, 1995, 1996, 1997, 1998, Wolfe & Hutchinson-Scarbrough 1999, Wolfe 2001, Wolfe et al. 2002, 2003, 2004, 2005, 2006, 2008, 2009a,b).

3.2. Struck and lost

Of 128 surveys that collected harvest information for all 4 species, 68 (53%) also collected struck and lost information. Another 88 surveys collected harvest information on spotted seals only, all of which included struck and lost. Except for NSB, all regions had at least 4 surveys that included struck and lost information.

Table 3. Annual average and liberal subsistence removal estimates (harvest plus struck and lost) of ice seals for 17 communities in the Kawerak region based on household surveys conducted from 1993–2014. Estimates for communities with no surveys during the study period were extrapolated from the rest of the region (shaded rows)

Community	No. of surveys (no. with struck and lost)	Alaska Native population 2015	Ringed seals		Bearded seals		Spotted seals		Ribbon seals	
			Average[a]	Liberal[b]	Average	Liberal	Average	Liberal	Average	Liberal
Brevig Mission[c–e]	3 (3)	398	102	193	85	124	129	183	11	32
Elim[d,e]	2 (2)	339	31	49	60	74	19	22	1	1
Gambell[c–e]	3 (3)	699	441	796	738	1209	631	951	27	40
Golovin[c,d,f]	3 (2)	160	31	86	19	34	28	52	2	4
Koyuk[e]	1 (1)	365	9	9	12	12	28	28	0	0
Little Diomede[f]	1 (0)	118	33	33	39	39	34	34	0	0
Nome	0 (0)	2263	632	1152	898	1370	877	1304	36	69
Savoonga[c–e,g]	4 (3)	704	367	679	406	754	416	896	29	53
Shaktoolik[c,d]	2 (2)	258	68	122	67	85	49	52	1	1
Shishmaref[e,f,h]	3(1)	605	405	593	547	683	640	777	12	21
Solomon	0 (0)	4	1	2	2	2	2	2	0	0
St. Michael[d,e]	2 (2)	412	2	3	34	49	45	50	0	0
Stebbins[c–f]	4 (3)	571	92	317	91	199	52	86	1	5
Teller[d,e]	2 (2)	235	22	45	38	67	66	103	1	3
Unalakleet[e]	1 (1)	706	10	10	90	90	119	119	3	3
Wales[d,e,i]	3 (2)	149	39	77	66	108	20	40	6	18
White Mountain[e]	1 (1)	203	1	1	58	58	20	20	0	0
Total	35 (28)	8189	2287	4167	3248	4957	3175	4720	130	250

[a]Average annual subsistence removal estimated from all available surveys for each community; [b]Liberal annual subsistence removal estimated from the highest estimate from all available surveys for that community; [c]Georgette et al. (1998); [d]Kawerak (2002); [e]Ahmasuk & Trigg (2007); [f]Braem et al. (2017); [g]Tahbone & Trigg (2011); [h]Magdanz & Alexander (1995); [i]Magdanz et al. (2002)

Sample sizes for BBNA (spotted seals) and AVCP (ringed, bearded, and spotted seals) surveys were sufficient for trend analysis. At the regional level, the proportions struck and lost showed no consistent patterns over the study period and no statistically significant trends, thus averaging struck and lost data across years within regions was justified. Statewide, the average proportion of struck and lost ranged from 0.062 for ringed seals to 0.125 for spotted seals (Table 6).

3.3. Average and liberal statewide removal estimates

Estimates of annual subsistence removal (including struck and lost) from 41 surveyed communities were extrapolated to communities without surveys to provide estimates for 55 ice seal hunting communities at both an average and liberal level (Tables 1–6). Based on average harvest, Kawerak had the highest subsistence removal for 3 of the 4 ice seal species and was a close second to AVCP for ringed seals (Table 6). BBNA had the lowest subsistence removal for ringed and bearded seals, NSB had the lowest subsistence removal for spotted seals; BBNA and NSB did not harvest ribbon seals (Table 6). The average statewide subsistence removal was highest for bearded seals, followed by ringed, spotted, and then ribbon seals (Table 6).

Sample sizes were sufficient for regional trend analysis for BBNA spotted seals and for NSB ringed and bearded seals. In these cases, the number of seals removed showed no consistent patterns through time and exhibited no statistically significant trends. Four communities had statistically significant trends in seals removed and per capita removal, all of which were negative (Togiak, Dillingham, and Twin Hills for spotted seals and Kotzebue for bearded and ringed seals). Except for the aforementioned trends, averaging the per capita removal estimates across years within regions was justified. Including the negative trends in per capita removal at the community level in the overall average resulted in a slight overestimate of removal, which is consistent with our conservative approach for evaluating subsistence take relative to PBR.

Table 4. Annual average and liberal subsistence removal estimates (harvest plus struck and lost) of ice seals for 20 communities in the Yukon-Kuskokwim Delta region (Association of Village Council Presidents) based on household surveys conducted from 1998–2014. Estimates for communities with no surveys during the study period were extrapolated from the rest of the region (shaded rows)

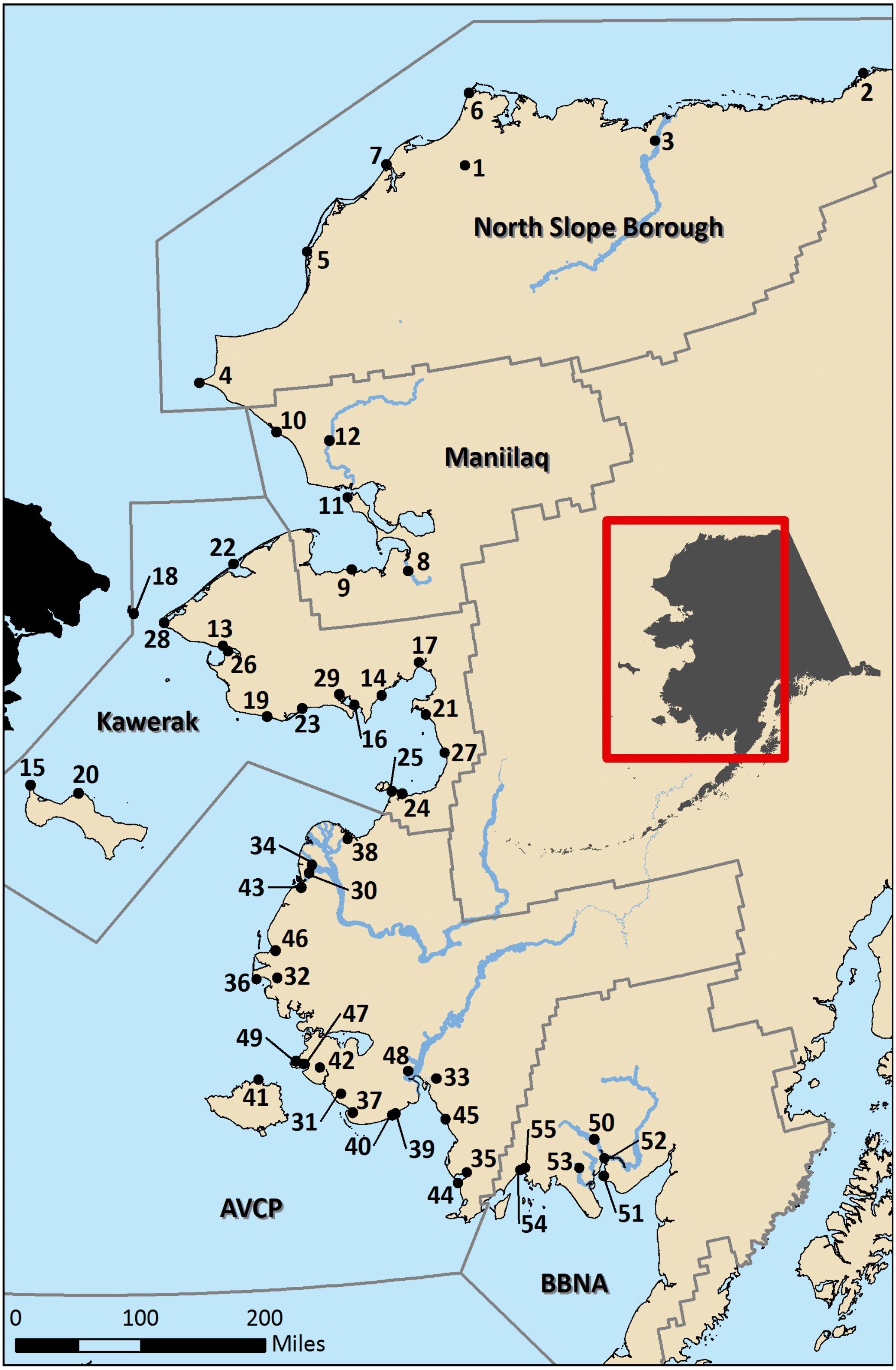
Community	No. of surveys (no. with struck and lost)	Alaska Native population 2015	Ringed seals		Bearded seals		Spotted seals		Ribbon seals	
			Average[a]	Liberal[b]	Average	Liberal	Average	Liberal	Average	Liberal
Alakanuk[c]	1 (0)	758	15	15	132	132	46	46	0	0
Chefornak	0 (0)	454	109	159	60	86	53	74	1	2
Chevak	0 (0)	1060	255	372	140	201	124	173	2	5
Eek[d]	1 (0)	321	13	13	17	17	24	24	0	0
Emmonak[e–h]	4 (3)	813	72	140	126	183	43	55	4	7
Goodnews Bay	0 (0)	266	64	93	35	50	31	43	1	1
Hooper Bay[e,f,g]	9 (9)	1189	558	951	183	355	77	154	1	5
Kipnuk	0 (0)	686	165	241	90	130	80	112	2	3
Kongiganak	0 (0)	408	98	143	54	77	48	67	1	2
Kotlik	0 (0)	619	149	217	82	117	72	101	1	3
Kwigillingok	0 (0)	331	80	116	44	63	39	54	1	2
Mekoryuk	0 (0)	199	48	70	26	38	23	33	0	1
Nightmute	0 (0)	302	73	106	40	57	35	49	1	1
Nunam Iqua	0 (0)	202	49	71	27	38	24	33	0	1
Platinum	0 (0)	66	16	23	9	13	8	11	0	0
Quinhagak[e,f,g]	8 (8)	698	118	169	39	80	142	265	1	3
Scammon Bay[d,g]	3 (2)	525	164	178	73	89	56	60	4	7
Toksook Bay	0 (0)	657	158	230	87	125	77	107	1	3
Tuntutuliak[d]	1 (0)	466	89	89	66	66	134	134	0	0
Tununak[g]	5 (5)	294	189	221	32	38	70	89	0	2
Total	32 (27)	10314	2484	3617	1360	1954	1205	1685	23	47

[a]Average annual subsistence removal estimated from all available surveys for each community; [b]Liberal annual subsistence removal estimated from the highest estimate from all available surveys for that community; [c]Wolfe & Scott (2010); [d]Ikuta et al. (2016); [e]Coffing et al. (1998); [f]Coffing et al. (1999); [g]Ice Seal Committee (2019); [h]Fall et al. (2013)

Table 5. Annual average and liberal subsistence removal estimates (harvest plus struck and lost) of ice seals for 6 communities in the Bristol Bay Native Association region based on household surveys conducted from 1992–2011

Community	No. of surveys (no. with struck and lost)		Alaska Native population 2015	Ringed seals		Bearded seals		Spotted seals		Ribbon seals	
	All seals	Spotted only		Average[a]	Liberal[b]	Average	Liberal	Average	Liberal	Average	Liberal
Aleknagik[c–s]	1 (0)	16 (16)	224	0	0	0	0	16	44	0	0
Clark's Point[c–s]	1 (0)	16 (16)	64	23	23	0	0	19	80	0	0
Dillingham[c–r,t]	1 (0)	17 (16)	1492	4	4	9	9	31	114	0	0
Manokotak[c–s]	2 (0)	17 (16)	453	15	26	15	18	34	79	0	0
Togiak[c–r,u,v]	6 (5)	20 (19)	850	2	6	6	29	159	433	0	0
Twin Hills[c–r,u,v]	5 (4)	15 (14)	95	1	3	0	0	19	55	0	0
Total	16 (9)	101 (97)	3178	44	62	30	56	277	805	0	0

[a]Average annual subsistence removal estimated from all available surveys for each community; [b]Liberal annual subsistence removal estimated from the highest estimate from all available surveys for that community; [c]Wolfe & Mishler (1993); [d]Wolfe & Mishler (1994); [e]Wolfe & Mishler (1995); [f]Wolfe & Mishler (1996); [g]Wolfe & Mishler (1997); [h]Wolfe & Mishler (1998); [i]Wolfe & Hutchinson-Scarbrough (1999); [j]Wolfe (2001); [k]Wolfe et al. (2002); [l]Wolfe et al. (2003); [m]Wolfe et al. (2004); [n]Wolfe et al. (2005); [o]Wolfe et al. (2006); [p]Wolfe et al. (2008); [q]Wolfe et al. (2009a); [r]Wolfe et al. (2009b); [s]Holen et al. (2012); [t]Evans et al. (2013); [u]Coiley-Kenner et al. (2003); [v]Ice Seal Committee (2019)



North Slope Borough	
Atqasuk	1
Kaktovik	2
Nuiqsut	3
Point Hope	4
Point Lay	5
Utqiaġvik (Barrow)	6
Wainwright	7
Maniilaq	
Buckland	8
Deering	9
Kivalina	10
Kotzebue	11
Noatak	12
Kawerak	
Brevig Mission	13
Elim	14
Gambell	15
Golovin	16
Koyuk	17
Little Diomede	18
Nome	19
Savoonga	20
Shaktoolik	21
Shishmaref	22
Solomon	23
St. Michael	24
Stebbins	25
Teller	26
Unalakleet	27
Wales	28
White Mountain	29
AVCP	
Alakanuk	30
Chefornak	31
Chevak	32
Eek	33
Emmonak	34
Goodnews Bay	35
Hooper Bay	36
Kipnuk	37
Kotlik	38
Kongiganak	39
Kwigillingok	40
Mekoryuk	41
Nightmute	42
Nunam Iqua	43
Platinum	44
Quinhagak	45
Scammon Bay	46
Toksook Bay	47
Tuntutuliak	48
Tununak	49
BBNA	
Aleknagik	50
Clark's Point	51
Dillingham	52
Manokotak	53
Togiak	54
Twin Hills	55

Fig. 1. The 5 regions and 55 communities where Alaska Native hunters regularly hunt ice seals for subsistence in Alaska. Numbers associated with each community correspond to the communities' location on the map. AVCP: Association of Village Council Presidents; BBNA: Bristol Bay Native Association

Table 6. Annual average and liberal subsistence removal estimates (harvest plus struck and lost) of ice seals by region and the average proportion struck and lost ('Lost') for each region. Totals include estimated seal removal by subsistence hunters statewide with the average statewide estimate of struck and lost for each species. The North Slope Borough (NSB) did not collect struck and lost information during their surveys. Shaded cells are the average of Maniilaq and Kawerak struck and lost estimates. This derived value was not used when calculating the statewide average proportions struck and lost. AVCP: Association of Village Council Presidents; BBNA: Bristol Bay Native Association

Region	Ringed seals			Bearded seals			Spotted seals			Ribbon seals		
	Average[a]	Liberal[b]	Lost[c]	Average	Liberal	Lost	Average	Liberal	Lost	Average	Liberal	Lost
NSB	1146	2343	0.079	1031	1820	0.098	89	245	0.096	0	0	
Maniilaq	493	1436	0.095	1038	1786	0.097	507	829	0.111	9	20	0.128
Kawerak	2287	4167	0.078	3248	4957	0.098	3175	4720	0.095	130	250	0.057
AVCP	2484	3617	0.054	1360	1954	0.111	1205	1685	0.109	23	47	0.137
BBNA	44	62	0.083	30	56	0.200	277	805	0.170	0	0	
Statewide total	6454	11625		6707	10573		5253	8284		162	317	
Weighted average[d]			0.062			0.102			0.125			0.071

[a]Average annual harvest estimated from all available surveys for each community, extrapolated to the region; [b]Liberal annual harvest estimated from the highest estimate from all available surveys for that community, extrapolated to the region; [c]Lost = loss proportions calculated as annual average number of struck and lost seals divided by the average annual removal; [d]Average statewide struck and lost proportions calculated using the regional lost proportions weighted by the total number of seals removed by each region

Table 7. Total annual (average and liberal) statewide removal estimates (harvest plus struck and lost), and potential biological removal (PBR) for ringed, bearded, spotted, and ribbon seals. Human-caused removals of < PBR are a conservative indicator that the removal is sustainable

	Ringed seals (PBR = 14100)			Bearded seals (PBR = 10720)			Spotted seals (PBR = 12697)			Ribbon seals (PBR = 9785)		
	N_{min}[a]	Removal Average[b]	Removal Liberal[c]	N_{min}	Removal Average	Removal Liberal	N_{min}	Removal Average	Removal Liberal	N_{min}	Removal Average	Removal Liberal
	470000	6454	11625	357328	6707	10573	423247	5253	8284	163086	162	317
Percent of PBR removed		45.8	82.4		62.6	98.6		41.4	65.2		1.7	3.2

[a]See Section 2.6 for the definition of N_{min}; [b]Average annual harvest estimated from all available surveys for each community, extrapolated to region and summed for a statewide estimate; [c]Liberal annual harvest estimated from the highest estimate from all available surveys for that community, extrapolated to region and summed for a statewide estimate

3.4. Sustainability of the subsistence harvest

Although PBR was originally proposed to evaluate commercial fishery bycatch and is not prescribed for regulating subsistence harvest, we applied it as a conservative measure of sustainability. To this end, removals of less than PBR can be used to represent conservative measures of sustainable take. The average annual subsistence removal was less than PBR for all 4 species, ranging from 1.7 % of PBR for ribbon seals to 62.6 % of PBR for bearded seals (Table 7). The liberal, or worst-case annual subsistence removal was also less than PBR for all species, ranging from 3.2 % of PBR for ribbon seals to 98.6 % of PBR for bearded seals (Table 7).

4. DISCUSSION

4.1. Sustainability of subsistence hunting

Human-caused removals of marine mammals are not considered to be problematic if the population can remain stable or grow despite those removals. PBR has been used to assess whether human-caused removals are sustainable. Using our liberal (worst-case) scenario, where removals are overestimated and abundance is underestimated, we found that annual liberal removals due to subsistence hunting were less than PBR for all 4 seal species (Table 7). Even though liberal subsistence removals were 98.6 % of PBR for bearded seals, the conservatism built into our calculations reduces cause for concern. Recall that the minimum abundance estimate for bearded seals did not include half of the Bering Sea, half of the Chukchi Sea, or any of the Beaufort Sea.

4.2. Limitations to estimating statewide annual subsistence removal

Documenting ice seal harvest by interviewing participating households using a questionnaire designed to document how many seals were harvested in the prior 12 mo and, sometimes, how many were struck and lost, is not ideal, as numbers may not be remembered accurately. In coastal Alaskan communities, however, seals are important for food, and hunters often share their catch with other families, which makes the number harvested more likely to be remembered. Although the reporting period is 12 mo, most hunting occurs in spring and fall. For example, bearded seals are large and highly favored, and it is likely that hunters remember how many they caught in the spring and fall of the previous year, especially in communities that need skins for boat covers. Similarly, the hunters are also likely to remember seals that got away (i.e. were shot at and not retrieved) in the previous spring and fall seasons.

The reported number of seals struck and lost, however, is difficult to interpret. World-wide, self-reporting of struck and lost animals is generally viewed with suspicion, in part because consequences of higher reported struck and lost often result in reductions of the allowable harvest, such that hunters are believed to likely underreport losses to protect their quota. Struck and lost data that are not self-reported, however, are nearly impossible to collect. During this study (1992–2014), the percentage struck and lost reported for bearded seals in 128 surveys averaged 10.2% (range 9.7–20.0% per region). This was lower than estimates of 25–50% based upon information from the 1960s and 1970s for bearded seals in Alaska (Burns 1967, Burns & Frost 1983). Studies that have addressed struck and lost in other marine mammals report similar findings. Fay et al. (1994) reported 42% lost for Pacific walruses, and Sjare & Stenson (2002) reported 0–22% for harp seals on ice and 5–50% for harp seals in the water; although it is difficult to know how comparable these results are to ours due to differences in behavior of the species and particulars of each hunt.

Although there was no consistent pattern of struck and lost at the regional level, some BBNA and AVCP communities exhibited significant trends in the proportion of struck and lost. For bearded and ringed seals all trends were negative and, because our regional proportions do not account for these trends, our estimates of removal could be slightly biased high, which is consistent with our conservative approach for evaluating subsistence take relative to PBR.

Predicting how struck and lost might have changed since the 1970s is also problematic. More hunting in open water could increase the chances of seals sinking, and a shorter spring hunting season (Huntington et al. 2017) may encourage riskier shots. On the other hand, more powerful and accurate firearms, faster boats, and efforts to reduce loss through hunter education (Ahmasuk 2006, Quakenbush et al. 2007) may decrease loss. Regardless, the number of seals reported by hunters as struck and lost are not likely to be lower than the 10% reported in our study. Until more current and specific information is available, struck and lost between 10 and 50% is the best available estimate.

We recognize that extrapolating harvest data from surveyed communities to communities not surveyed, which occurred in 2 regions, required caution because of the potential to introduce bias. We only extrapolated subsistence removal within a region, to minimize potential bias associated with differences among regions. For example, spotted seals are mostly hunted during the open water season and thus are available longer in the southern BBNA region than in regions farther north because sea ice leaves sooner and forms later. Thus, extrapolating among regions might bias estimates. Although only 8 of 20 communities in the AVCP region were surveyed, those 8 communities represented 49% of the region's human population, and population sizes were fairly representative of all the region's communities, which makes these extrapolations somewhat robust to bias. On the other hand, bias may have resulted from not surveying Nome, the largest community in the Kawerak region. It is possible that subsistence removal of ice seals in Nome is different than in smaller communities because Nome has a larger economy including more job opportunities and more grocery options (https://factfinder.census.gov/faces/nav/jsf/pages/index.xhtml) that could lead to less dependence on seals for food. If per capita subsistence removal in Nome is less than in the smaller Kawerak communities, then we may have overestimated harvest for the entire Kawerak region by using the regional per capita estimate for the extrapolation.

We also presented a liberal subsistence removal estimate in addition to the average so as to purposely overestimate subsistence removal and better understand the level of sustainability. If worst-case estimates had exceeded PBR, a closer examination would be warranted.

4.3. Setting recovery factors and estimating PBR

It appears that setting F_r at 0.5 for ringed, bearded, and spotted seals, when their populations are not known to be declining and human-caused mortality is primarily harvest by subsistence hunters, has been overly conservative. The Guidelines for Assessing Marine Mammal Stocks (GAMMS) state 'stocks that are not known to be decreasing taken primarily by aboriginal subsistence hunters, could have higher F_r values [higher than F_r = 0.50], up to and including 1.0, provided there have not been recent increases in the levels of takes' (NMFS 2016, p. 8). This logic was used to set the recovery factor for ribbon seals to 1.0 (Peter Boveng pers. comm.). Like ribbon seals, there is no evidence that the populations of bearded, ringed, and spotted seals are declining, so there is little justification for using values of F_r other than 1. In fact, evidence supports healthy populations (Quakenbush et al. 2009, Crawford et al. 2015) and their circumstances would appear to fit the logic used for setting the F_r for ribbon seals. If F_r is also set to 1.0 for ringed, bearded, and spotted seals, then subsistence removal of all 4 species would be well below their recommended PBRs.

Bearded and ringed seals differ from spotted and ribbon seals in that they are ESA-listed as threatened; however, the GAMMS provides for modifying the default recovery values for listed species, stating 'Recovery factors for ESA-listed stocks can be changed from their default values, but only after careful consideration and where available scientific evidence confirms that the stock is not in imminent danger of extinction' (NMFS 2016, p. 8). Until recently, marine mammal populations listed as threatened have been shown to be declining or depleted, and it appears that the default value for F_r presumes this relationship. Unlike most ESA listings, the ringed and bearded seal listings did not identify, or depend on, a population decline. Instead, the listings for bearded and ringed seals were based on predicted population declines within the subsequent 100 yr based on how each species would respond to changes in environmental factors (e.g. decreased sea ice and snow deposition) predicted by climate models, but without consideration of the current status or trend of each population. The ringed and bearded seal listing decisions represent a new class of listings that require unique treatment when setting default values for calculating PBR. Therefore, a review of the recovery factors (i.e. F_r) used when calculating PBR for ice seals, keeping in mind that ice seals are an important subsistence resource and that no stock is in imminent danger of extinction, appears to be warranted.

4.4. Recommendations

Because most human-caused removals of ice seals are a result of subsistence harvests, maintaining harvest monitoring programs in Alaska is paramount for assessing sustainability. Our experience estimating harvest plus struck and lost should be used to improve future estimates of subsistence removals for evaluating sustainability.

4.4.1. Community surveys

A comprehensive state-wide survey strategy should be developed to estimate the number of seals removed for subsistence annually and to quantify inter-annual variability and trends. To quantify variability, this strategy should (1) survey more communities, (2) survey the same communities in several consecutive years, and (3) collect struck and lost information. For example, one-third of all communities could be surveyed for 3 consecutive years, and then those communities would be surveyed again 10 yr later. Such a schedule would provide consistent monitoring for some communities within each region, in any given year, and would include all communities on a 10 yr rotation. The highest priority region for additional surveys is AVCP because it has the most seal hunting communities and the fewest community surveys.

Harvest surveys should be coordinated among entities conducting surveys (e.g. NSB, ISC, BBNA, State of Alaska). Results should be presented with clear and complete methods to ensure that harvest data are used appropriately, including (1) how households were selected, (2) what proportion of all households were surveyed, (3) how extrapolations were calculated, and (4) how struck and lost was counted.

4.4.2. Struck and lost

Clearly, more effort is needed to quantify struck and lost, how best to report it, and what measures can be taken to reduce it. Such research will require collaboration with hunters, community leaders, the ISC, and managers to identify an approach that will provide species-specific estimates of struck and lost that are acceptable to hunters and managers.

4.4.3. Seal abundance estimates

In addition to the need for continued harvest monitoring, improved estimates of seal population abundance would increase confidence that removals are sustainable. Increased precision in seal abundance drives N_{min} upward, increasing PBR and providing a stronger basis for managers to choose less conservative values for F_r, which also increases PBR.

5. CONCLUSIONS

Given the high degree of conservatism built into our analysis, we conclude that the subsistence removals including seals struck and lost are sustainable for all 4 species of ice seals in Alaska. Our analysis of harvest trend indicates that for most communities the subsistence removal of ice seals has remained relatively stable since 1992. The only significant trends in subsistence removal were negative. Therefore, we think it likely that subsistence hunting of ice seals will remain sustainable unless large increases in harvests or struck and lost occur concurrent with decreases in population abundance.

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