2006-2010 HARVEST ATTRIBUTIONS FOR BAFFIN BAY NARWHALS

Context

The Nunavut Wildlife Management Board (NWMB) plans to begin the process of establishing Total Allowable Harvest (TAH) levels for narwhals. In preparation for that, Fisheries and Oceans Canada (DFO) presented to the NWMB a working hypothesis that narwhal summering aggregations represent distinct biological units (i.e., provisional management units/stocks), along with sustainable catch recommendations for each of these units. Narwhals are harvested by communities located near their summering aggregation areas and by more distant communities during the spring/fall migrations. Therefore, the total hunting pressure on individual units cannot be assessed directly.

DFO Ecosystems and Fisheries Management recently requested advice on how best to determine community allocations so that harvest from each of the summering aggregations is consistent with the sustainable catch recommendation. A community harvest allocation model was recently developed to attribute narwhal catches to each of the communities that harvest from known Baffin Bay summering stocks (provisional management units); this model was peer-reviewed on May 6, 2011 to assess its potential to guide co-management decisions on future community harvest allocations. The purpose of the model is to provide a management tool for allocating catch from different communities without exceeding the total allowable landed catch from any stock. Although the May 6th meeting documents had not yet been finalized and approved, participants of the peer review concluded that model provided a reasonable basis for allocating the catch, but recommended further work on the sensitivity of the model to departures from model assumptions.

Following the above-mentioned meeting, Science at National headquarters requested a retrospective analysis of the sustainability of the 2006-2010 narwhal catches using the allocation model to attribute recorded catches and seasonal catch proportions.

This Science Response report is from the Fisheries and Oceans Canada, Canadian Science Advisory Secretariat (Zonal Science Special Response Process [SSRP] of May 19, 2010 on the 2006-2010 harvest attributions for Baffin Bay narwhals).

Background

Baffin Bay Narwhal Population

Current understanding of the Baffin Bay population is described in DFO (2012a). The Baffin Bay narwhal population occupies Baffin Bay and adjacent waters in winter. In summer, a large component of the population aggregates in Canada, in areas ranging from East Baffin Island coastal waters to the High Arctic archipelago (Richard et al. 2010). The remainder summer in West Greenland waters, particularly in Inglefield Bredning and Melville Bay.

The Canadian portion of the Baffin Bay population consists of at least four narwhal stocks which aggregate in summer: the Somerset Island, Admiralty Inlet, Eclipse Sound and East Baffin Island stocks (DFO 2010, Richard 2010) (Fig. 1). Narwhals are also known to occur elsewhere in the High Arctic during summer (Fig. 1; DFO 2012a); however, there is no current assessment of their numbers, seasonal movements or their relationship to other Baffin Bay narwhals. Therefore, the present analysis only considers the four known narwhal stocks that comprise the Canadian component of the Baffin Bay population. The Northern Hudson Bay narwhal population is recognize as a geographically separate and genetically distinct population (DFO 2012a) and is also not being considered here.

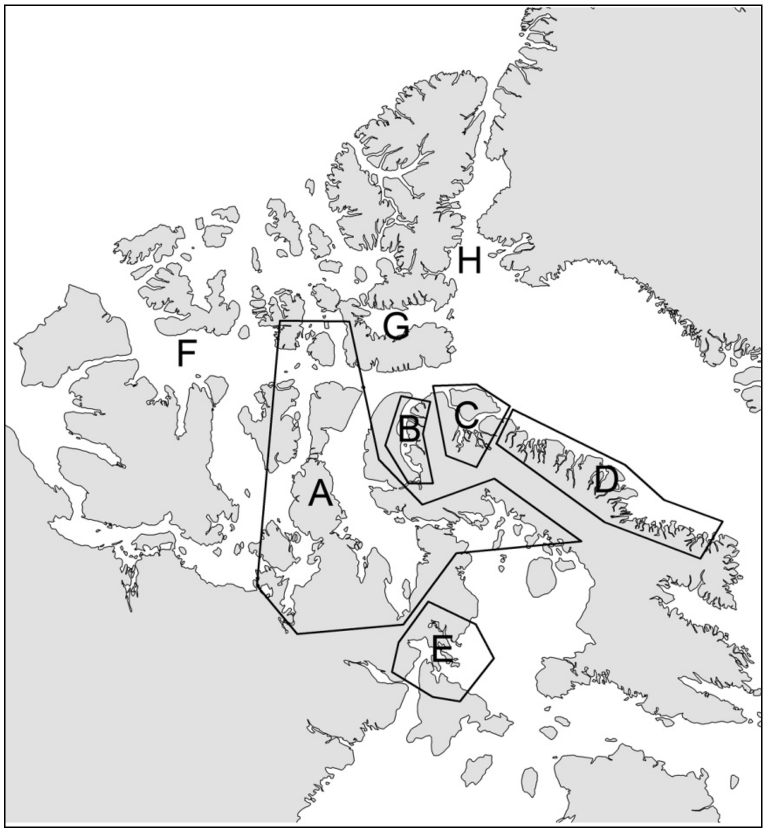


Fig. 1. Approximate boundaries of areas where Canadian stocks of narwhals aggregate in summer: A - Somerset Island, B - Admiralty Inlet, C - Eclipse Sound, D - East Baffin Island, E - Northern Hudson Bay. Other areas where narwhals are known to occur in summer: F - Parry Islands, G - Jones Sound, H - Smith Sound) (Figure from DFO 2012a).

Evidence from tracking data (Richard 2010; Heide-Jørgensen and Richard, unpubl. data), suggests that narwhals generally show site fidelity (i.e. natal philopatry) to summering areas, and there is thought to be limited stock mixing in summer (DFO 2010, Richard 2010). Further evidence from contaminant data (de March 2003a) supports this hypothesis. The most recent population estimates for the Canadian portion of the Baffin Bay population (Table 1) are based on the assumption that narwhals show fidelity to summering areas (see DFO 2012a for a description of narwhal survey history and overall population estimates assuming either philopatry or panmixia).

Table 1: Summary of abundance estimates (with coefficients of variation, and lower and upper confidence limits) for the Canadian portion of the Baffin Bay narwhal population. Note: No single survey covered the entire range of narwhals in summer. Some surveys covered the summer aggregations and are summed to give an estimate (albeit incomplete) of the Canadian component of the Baffin Bay narwhal population. PBR and TALC were calculated assuming stock philopatry. All data taken from DFO (2012a).

Stock	Months Surveyed	Year	Estimate	CV	LCL	UCL	Source	PBR	TALC
Somerset	late July-early August	1996	45,358	0.35			Innes et al. 2002	681	532
East Baffin	August	2003	10,073	0.31	5,333	17,474	Richard et al. 2010	156	122
Eclipse Sound	August	2004	20,225	0.36	9,471	37,096	Richard et al. 2010	301	236
Admiralty Inlet	August	2010	18,049	0.23	11,613	28,053	Asselin and Richard 2011	299	233

Analysis and Responses

Methods

Spatial Analysis of Narwhal Seasonal Distribution

Baffin Bay narwhals aggregate in at least four areas in summer in the Qikiqtani (Baffin) and Kitikmeot (central Arctic) regions of Nunavut (Richard 2010, 2011). The allocation model presented by Richard (2011) only concerns the four largest Baffin Bay narwhal aggregations in Nunavut (Innes et al. 2002, Richard et al. 2010, Richard 2010): these are the Somerset Island (SI), Admiralty Inlet (AI), Eclipse Sound (ES) and East Baffin Island (EB) narwhal stocks (Fig. 2). Richard's (2011) allocation model did not consider the narwhals harvested by Grise Fiord, as these are likely from a different (and currently unspecified) stock of narwhals. Also, it did not consider the Northern Hudson Bay narwhal population, which is assumed to be geographically separate year-round from Baffin Bay narwhal stocks and exhibits different genetic and contaminant profiles (de March et al. 2003, de March and Stern 2003).

The four summering stocks considered in Richard's (2011) allocation model (SI, AI, ES and EB) appear to be relatively sedentary in summer and are hunted in their summer range (Fig.1) by local communities as follows.

- the Admiralty Inlet (AI) summering stock is harvested by hunters in Arctic Bay (AB)
- the Eclipse Sound (ES) summering stock is harvested by hunters in Pond Inlet (PI)
- the East Baffin (EB) summering stock is harvested by hunters in Clyde River (C) and Qikiqtarjuaq (Q)
- the Somerset Island (SI) stock is harvested by hunters in Resolute (RB; particularly in the Creswell Bay area), the Kitikmeot communities of Gjoa Haven (GH), Taloyoak (T) and Kugaaruk/Pelley Bay (KK), and the Northern Foxe Basin communities of Igloolik (IG) and Hall Beach (HB) (Fig. 2). All six communities are referred to as the Western Communities in this paper and their harvest is called the "Western annual catch".

Outside of the summer, open-water season, all Baffin Island communities hunt mixed stocks (Richard 2011; Fig. 2). The proportion of narwhals belonging to any particular stock in the non-summer harvest period is unknown, but it is assumed to be proportional to the size of each stock relative to the total number of animals in the mixture of stocks. Risk modeling is used to evaluate the sensitivity of the modeling analyses to this assumption.

Narwhal Catch Allocation Model

As previously mentioned, the Canadian portion of the Baffin Bay narwhal population is thought to be comprised of four summering stocks. Because narwhals are hunted in both the summer, open-water period (when the harvest consists of stable, aggregated, generally non-mixed stocks) and non-summer periods (when the harvest would consist of mixed stocks), the allocation of total allowable landed catch (TALC) limits to communities harvesting these stocks is somewhat complicated (Richard 2011).

At the western end of the range of narwhals, the communities of Resolute, Gjoa Haven, Taloyoak, Kugaaruk, Igloolik and Hall Beach generally hunt during the summer period; therefore, narwhals hunted are likely from the Somerset Island stock (Richard 2011). Hall Beach hunters have occasionally harvested narwhals from Lyon Inlet in the summer (Gonzales 2001), but these were likely from the Northern Hudson Bay stock.

In contrast, the Baffin Island communities may harvest narwhals in both the summer and non-summer periods (Romberg and Richard 2005). Therefore, during non-summer migration periods, Baffin Island communities (Arctic Bay, Pond Inlet, Clyde River, Qikiqtarjuaq, Pangnirtung and Iqaluit) likely harvest narwhal from a mixture of stocks.

Richard (2011) presented an allocation model that can be used as a decision tool to assist co-managers in deciding on the allocation of total allowable landed catches (TALCs) for the four Baffin Bay summering stocks, given that part of several communities' narwhal catches come from non-summer mixed stocks of narwhals. The allocation tool is based on a spatial model of the source and degree of stock mixtures that are hunted and produce possible solutions that maximize the catch, particularly for communities with large historic narwhal catches, while minimizing the risk of over-exploitation of any one stock. This model is used here to determine the sustainability of the 2006-2010 Baffin Bay narwhal harvests.

Allocation Model Description, Inputs and Analysis of Previous Harvests

In Richard's (2011) allocation model, summer proportion (SP) of the hunt by a community or set of communities (AB, PI, CR and Q) was entered in the model as a decision rule, i.e., a chosen value between 0% and 100%. The non-summer proportion was calculated simply as 1-SP (Richard 2011).

During the non-summer period, hunts by Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq communities may be affected by logistic constraints (e.g., how long the floe edge hunt lasts, or how many animals can be taken in fall weather). As such, the proportion of the total annual catch that is allocated to summer or non-summer periods in these communities is not a good variable to optimize mathematically, and therefore the SP for these communities are entered as fixed values in the model (Richard 2011).

In contrast, the Resolute, Kitikmeot (Gjoa Haven, Taloyoak and Kugaaruk) and Northern Foxe Basin (Igloolik and Hall Beach) catches are relatively small and primarily from the largest stock (SI). The Somerset Island stock also supports non-summer hunts elsewhere (see Fig. 2). The catch limit for that area, called the "Western annual catch", was also designated a decision variable rather than being mathematically optimized (Richard 2011). Finally, due to the relatively small catches in Pangnirtung and Iqaluit, their landed catches were also used as a decision variable (Richard 2011).

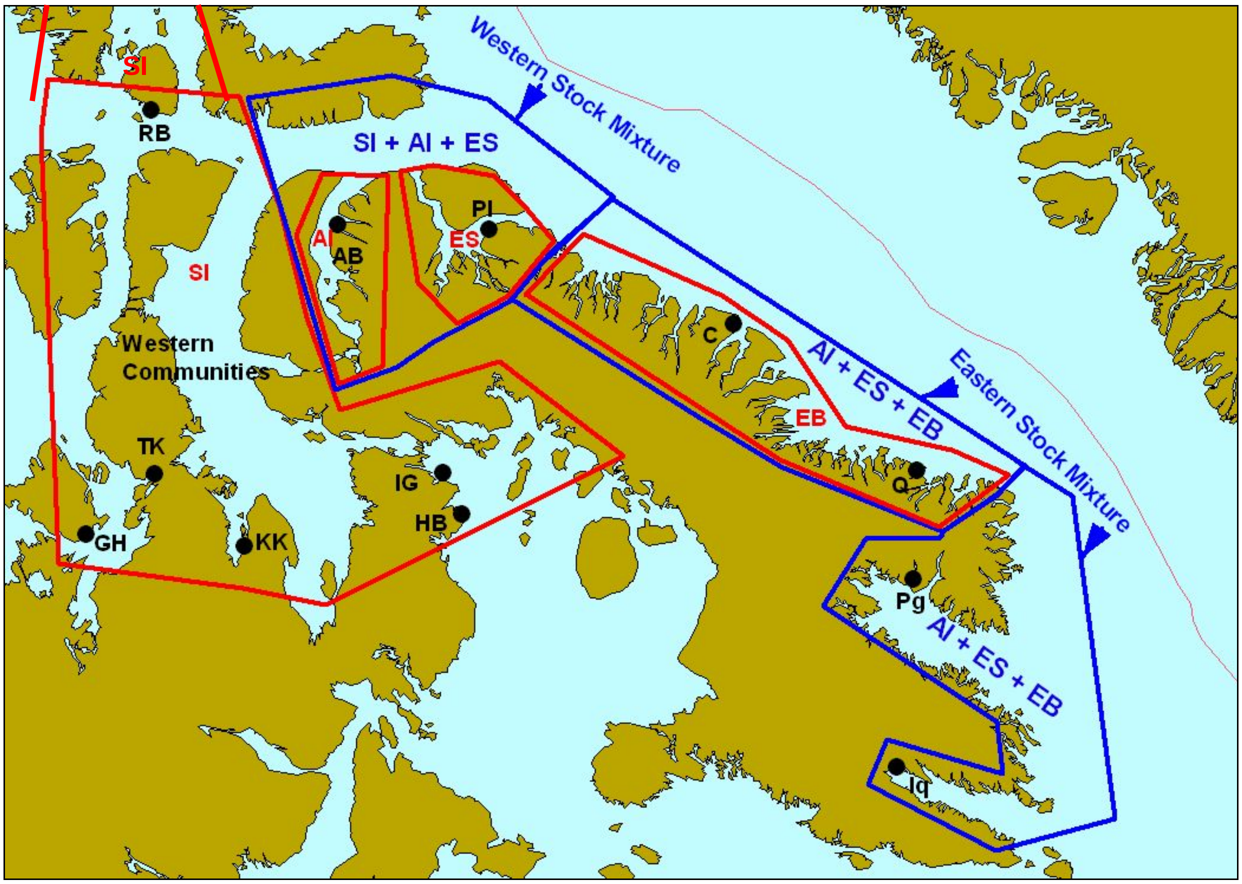


Fig.2: Schematic representation of the summering stocks discussed in the text (in red letters: SI: Somerset Island stock; AI: Admiralty Inlet stock; ES: Eclipse Sound stock; EB: East Baffin Island stock) and of non-summer stock mixtures (in blue letters). Communities that hunt the stocks are indicated in black letters (RB: Resolute; TK: Taloyoak; GH: Gjoa Haven; KK: Kugaaruk; IG: Igloolik; HB: Hall Beach; AB: Arctic Bay; PI: Pond Inlet; C: Clyde River; Q: Qikiqtarjuaq; Pg: Pangnirtung; Iq: Iqaluit)(Figure from Richard 2011).

When using the model to examine options for future catches, the allocation model can be run to optimize the landed catch by the Nunavut communities of Arctic Bay, Pond Inlet, and the two East Baffin communities (Clyde River and Qikiqtarjuaq). The model uses a linear optimization tool to solve the model by finding the optimal division of annual landed catches. The optimal solution is a vector of landed catches (one catch for each of AB, PI, CR and Q) that maximizes the sum of landed catches while minimizing the difference between each stock's TALC and the total catch (TC) on it (optimized or decision) (Richard 2011). The optimization is constrained by limiting solutions to positive or zero values of TALC-TC. In other words, the optimization allows as much landed catches by those communities as possible within the limits of the TALCs of the four stocks affected, and without any one stock's TALC being exceeded (i.e., TALC-TC ≥0).

For different trial vectors of community catches, the model (Richard 2011) calculated the total catch from each stock and calculates the TALC-TC as follows:

$TC_s = SC_s + NSC_s$
so
$TALC_s - TC_s = TALC_s - (SC_s + NSC_s)$
where:

$TALC_s$: Total Allowable Landed Catch on stock s
s: Stocks "SI" (Somerset Island), "AI" (Admiralty Inlet), "ES" (Eclipse Sound), or "EB" (East Baffin

Island)
TC_s: Total catch on stock s
SC_s: Summer catch on stock s
NSC_s = Non-summer catch on stock s

and:
$SC_s = \sum SC_c = \sum (SCP_c * AC_c)$
$NSC_s = \sum ((1- SCP_c) * NSSP_m * AC_{cm})$

where:
SC_c: Summer catch by community c
c = Communities AB (Arctic Bay), PI (Pond Inlet), CR (Clyde River) and Q (Qikiqtarjuaq)
SCP_c: Summer catch proportion by community c
AC_c: Annual catch by community c
$NSSP_m$ = Non-summer stock proportion in mixture m
m: "W" (Western Stock mixture) or "E" (Eastern Stock mixture)
$NSSP_m = SS_s / \sum (SS_{sm})$ where $SS_s = 0$ if stock not in mixture
where:
SS_{sm} = estimated stock size of stock s in mixture m

To be more specific:
$SC_{SI} = AC_W$
$SC_{AI} = SCP_{AB}*AC_{AB}$
$SC_{ES} = SCP_{PI} * AC_{PI}$
$SC_{EB} = (SCP_C * AC_C) + (SCP_Q * AC_Q)$

$NSC_{SI} = NSSP_W * (NSC_{AB} + NSC_{PI})$
$NSC_{AI} = NSSP_W * (NSC_{AB} + NSC_{PI}) + NSSP_E *(NSC_C + NSC_Q + AC_{Pg\&Iq})$
$NSC_{ES} = NSSP_W * (NSC_{AB} + NSC_{PI}) + NSSP_E * (NSC_C + NSC_Q + AC_{Pg\&Iq})$
$NSC_{EB}= NSSP_E * (NSC_C + NSC_Q + AC_{Pg\&Iq})$

where:
SC_s: Summer catch from stock s
NSC_s = Non summer catch from stock s
AC_W = Annual catch for western communities
AC_{AB} = Annual catch for Arctic Bay (AB)
AC_{PI} = Annual catch for Pond Inlet (PI)
AC_C = Annual catch for Clyde River (C)
AC_Q = Annual catch for Qikiqtarjuaq (Q)
$AC_{Pg\&Iq}$= Annual catch for Pangnirtung-Iqaluit (Pg&Iq)

To summarize, the allocation model allows users to set decisions about the values of future landed catches by communities at both ends of the range of the four stocks and set the proportions of the catch that is to be taken in the summer season. Once those decision parameters are set, the optimization model can be run to maximize the sum of AC_{AB}, AC_{PI} , AC_C and AC_Q while minimizing $TALC_s$-TC_s that are positive or zero. In its current application, the model is used to determine the sustainability of the 2006-2010 Baffin Bay narwhal harvests. In this case the model simply calculates these results described above using real data. The model was run using the software Analytica 4.3 Player (www.lumina.com)

Sensitivity Analysis

A. Sensitivity to assumption of proportional stock sizes

The model results presented are based on the assumption that non-summer catches are taken in proportion to the size of each stock relative to the total number of animals in the mixture of stocks. For example, the Somerset Island, Admiralty Inlet, and Eclipse Sound stock mean abundances have been estimated at 45,358 narwhals, 18,049 narwhals and 20,225 narwhals, respectively (see Table 1). The Admiralty Inlet mean stock size represents 22% of the Western Stock mixture; therefore the model assumes that 22% of the non-summer catch for AB and PI is from the Admiralty Inlet stock. However, this may not be the case as the proportion may vary depending on the timing of migration by different stocks and on the timing of the hunt in the spring and fall. Given the uncertainty in stock proportions, what is the risk associated with this major assumption?

To illustrate that risk, two separate sensitivity analysis models were developed. In the first version, the catches for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq were entered as fixed values and the mixture stock proportions were modeled as lognormal distributions (Richard 2011). The means of the lognormals were set equal to the stock proportion in each mixture and the standard errors were set iteratively until their probability densities ranged from 0 to 1, with small probability densities near 0 and 1. These uncertainty distributions were further normalized by dividing each resample of these lognormal distributions by the sum of the re-sampled stock proportions. This ensured that all proportion re-samples summed to 1 and changed the probability density only slightly (see Fig. 6 in Richard 2011). These normalized lognormals were used to model the uncertainty in stock proportions in the non-summer catches.

The probability of a total catch on a stock exceeding the TALC for each stock was calculated from the resulting distribution of the TALC-TC on each stock that resulted from the re-samples of the stock proportions. The risk model calculated the probability of exceeding the TALC for a given stock as the fraction of the TALC-TC probability density for values smaller than zero. In simpler terms, the model drew 10,000 possible states of stock proportions and calculated the percentage of them that exceeded the TALCs of one or more of the four stocks.

The second version of the sensitivity analysis model modified the stock proportion of the SI stock to make it more conservative. Since this is the largest stock contributing to the mixture in the first version of the sensitivity analysis, the distribution of its proportion was modeled so it had higher probability density in the low range, i.e., SI stock proportion <= 50%. This was achieved by using a normalized Gamma (1, 0.2) distribution. The result is a cumulative density distribution of the SI stock proportion in the Western Stock mixture that has a median around 25.5%, while version one's lognormal has a median of 57.3% (see Fig. 7 in Richard 2011). In other words, the SI stock in this more conservative version contributes less to most Western Stock mixtures drawn by re-sampling.

Richard (2011) showed that, in general, the results from both versions of the sensitivity models (lognormal and gamma) suggest that accepting the stock proportion assumption has little or no risk of stock decline at the catch levels examined. The larger the summer proportions of the annual catch, the smaller the risk. Conversely, taking a larger proportion in the non-summer seasons is riskier. The risk is high for the smaller stocks (ES, AI) in the Western non-summer mixture in the gamma model runs, where the SI stock contributes fewer animals.

B. Sensitivity to assumption of separate Admiralty Inlet and Eclipse Sound stocks

Tracks acquired in the summer of 2011 showed four narwhals tagged in the Eclipse Sound area moved into Admiralty Inlet and remained there, unlike other animals tagged the same year and narwhals tagged at the same location in past years, which remained in Eclipse Sound the whole summer (DFO, unpublished). These appear to be unusual events, but this observation raises the possibility that these two summering stocks are not completely segregated in summer. To evaluate the sensitivity of the results to the assumption of separate summering stocks for Admiralty Inlet and Eclipse Sound, the attribution model was revised to treat these two summering aggregations as one stock. This revised model applied estimates of numbers of narwhals from surveys conducted in different years, as is warranted if one knows that there are philopatric summering stocks. But, if one assumes that there is one stock distributed in Admiralty Inlet and Eclipse Sound in summer then it is precautionary to use estimates from the same year of survey to avoid the possibility of double-counting. In 2004, there were surveys in both areas. However, the Admiralty Inlet survey that year was incomplete and was conducted under marginal visibility conditions. The estimate and corresponding TALC for Admiralty Inlet were much lower than for other surveys of the area. Consequently, using those numbers in the following analysis represents a highly conservative scenario with respect to the abundance of narwhal in these areas.

Table 2: Parameters calculated from the 2004 Admiralty Inlet surveys, following methods in Innes et al (2002) and Richard et al (2010).

$N_{surface}$	$CV(N_{surface})$	Ca	CV(Ca)	N_{AI}	CV(Nadj)	Nmin	PBR	TALC
542	0.72	3.03	0.045	1642	0.52	1252	25	20

To treat the two areas as separate stocks, the model was revised as follows:

$N_{AI\&ES} = N_{AI} + N_{ES}$
where N_{AI} = 1642, N_{Es} = same as base model

$TALC_{AI\&ES} = TALC_{AI} + TALC_{ES}$
where $TALC_{AI}$ = 20, $TALC_{Es}$ = same as base model

$SC_{AI\&ES} = SCP_{AB} * AC_{AB} + SCP_{PI} * AC_{PI}$

and

$NSC_{AI\&ES} = NSSP_{W} * (NSC_{AB} + NSC_{PI}) + NSSP_{E} * (NSC_{C} + NSC_{Q} + AC_{Pg\&Iq})$

Historical Narwhal Catch Data Used in Retrospective Analysis

Sequentially numbered narwhal tags are issued annually to each community based on identified community quotas (see http://laws-lois.justice.gc.ca/eng/regulations/SOR-93-56/index.html) to account for landed catches. For each tag used, hunters report the date of each narwhal killed, the sex of the animal, tusk length (if male) and community. Unused tags are returned DFO and recorded as such. Therefore, the tag database consists of a complete record of all tag numbers issued and whether they were used in a given year by a given community.

The verified and proof read annual narwhal tag data from 2006-2010 were used to determine the total annual community catches of narwhals and seasonal hunting trends in individual Baffin Bay communities. Summer hunt proportions were determined by examining peaks and troughs in hunting activity in each community in each year; the end of a season and the beginning of another is determined by a trough in catches between two peaks according to the methods of Romberg and Richard (2005). In that study, the distribution of narwhal harvest was broken down into three "seasons" based on day of year: pre-day 205 (spring), or roughly the spring floe edge and crack hunt; between day 205 and 274 for summer open water hunts; and post-day 274 (fall) to estimate the proportion of harvest during these periods by each community. The proportion of the hunt that occurred in summer for each community was then calculated.

To assess the reliability of narwhal tag returns, the number of tags allocated to each community that were confirmed to be either returned used or unused were also calculated, with the remainder being "fate unknown".

Results

Annual and Seasonal Community Harvests of Narwhals

Table 3 and Figures 3a-c present the total landed catch of narwhals in each community in each year, and for all years and communities combined. Annual landed catch of narwhals in several communities appeared relatively stable from 2006-2010 (e.g. Arctic Bay), whereas other communities showed pronounced interannual variability (e.g. Pond Inlet, Clyde River). Among the western communities, those which regularly harvest narwhals annually (e.g. Igloolik, Taloyoak) showed a marked decline in harvest from 2006 to 2007, but remained relatively stable and low thereafter. Figure 4 illustrates the temporal trends and variability among community narwhal harvests from 2006-2010. Figure 5 illustrates the annual differences between overall seasonal (spring, summer, fall) community harvests. For all years and all communities combined, 18% of the narwhal harvest takes place in spring (< day of year 205), 72% in summer (day of year 205-274), and 10% in fall (> day of year 274).

Table 3. Total reported landed catch of narwhals in each community from 2006-2010.

Community	2006	2007	2008	2009	2010	Total
Arctic Bay	130	127	132	129	128	646
Clyde River	43	42	17	13	50	165
Iqaluit	0	3	0	0	0	3
Pangnirtung	1	1	21	0	28	51
Qikiqtarjuaq	85	88	80	90	89	432
Pond Inlet	88	65	70	44	62	329
Pond Inlet (ice entrapment) *	n/a	n/a	622	n/a	n/a	622
Gjoa Haven	0	1	0	1	1	3
hall Beach	1	0	0	0	2	3
Igloolik	25	1	0	1	0	27
Kugaaruk Pelley Bay	48	40	35	42	45	210
Resolute Bay/Creswell Bay	28	9	10	11	8	66
Taloyoak	34	0	3	5	2	44
Total	**483**	**377**	**990**	**336**	**415**	**2601**

* Represents the humane harvest due to the narwhal ice entrapment in PI in 2008

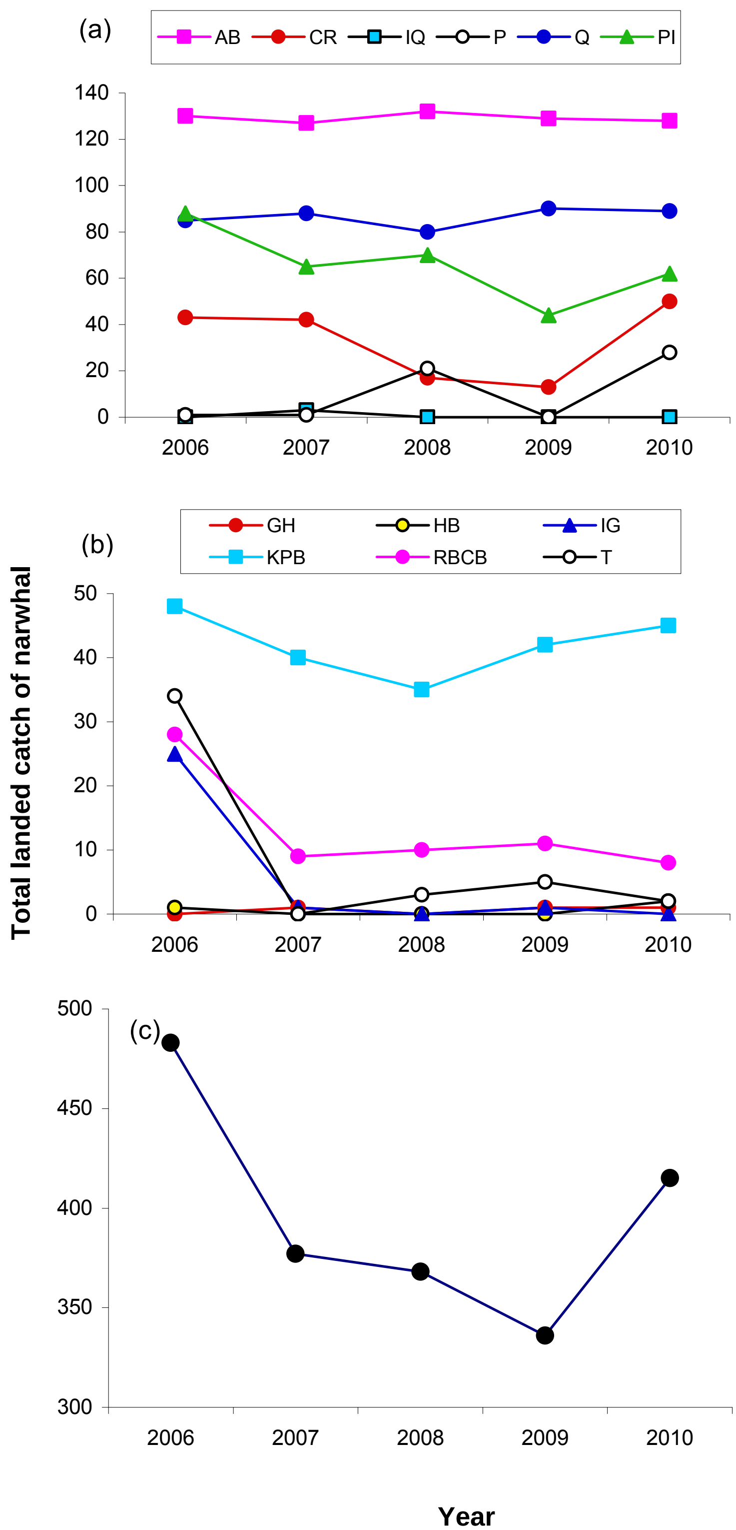


Fig. 3. Annual reported landed catch of narwhals in each community (a, b) and for all communities combined (c) from 2006-2010. Note that the 2008 data does not include narwhals harvested in the Pond Inlet ice entrapment.

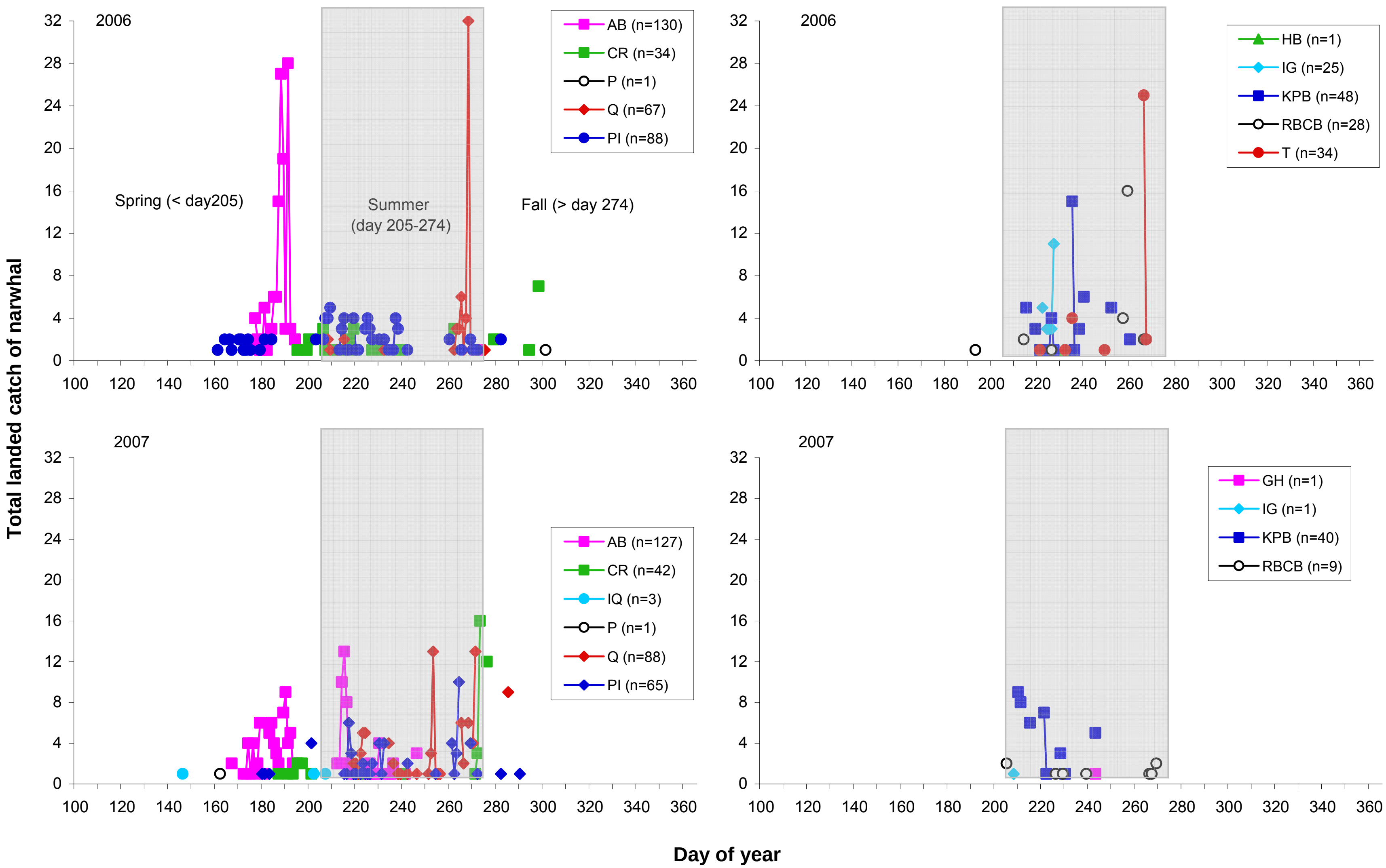
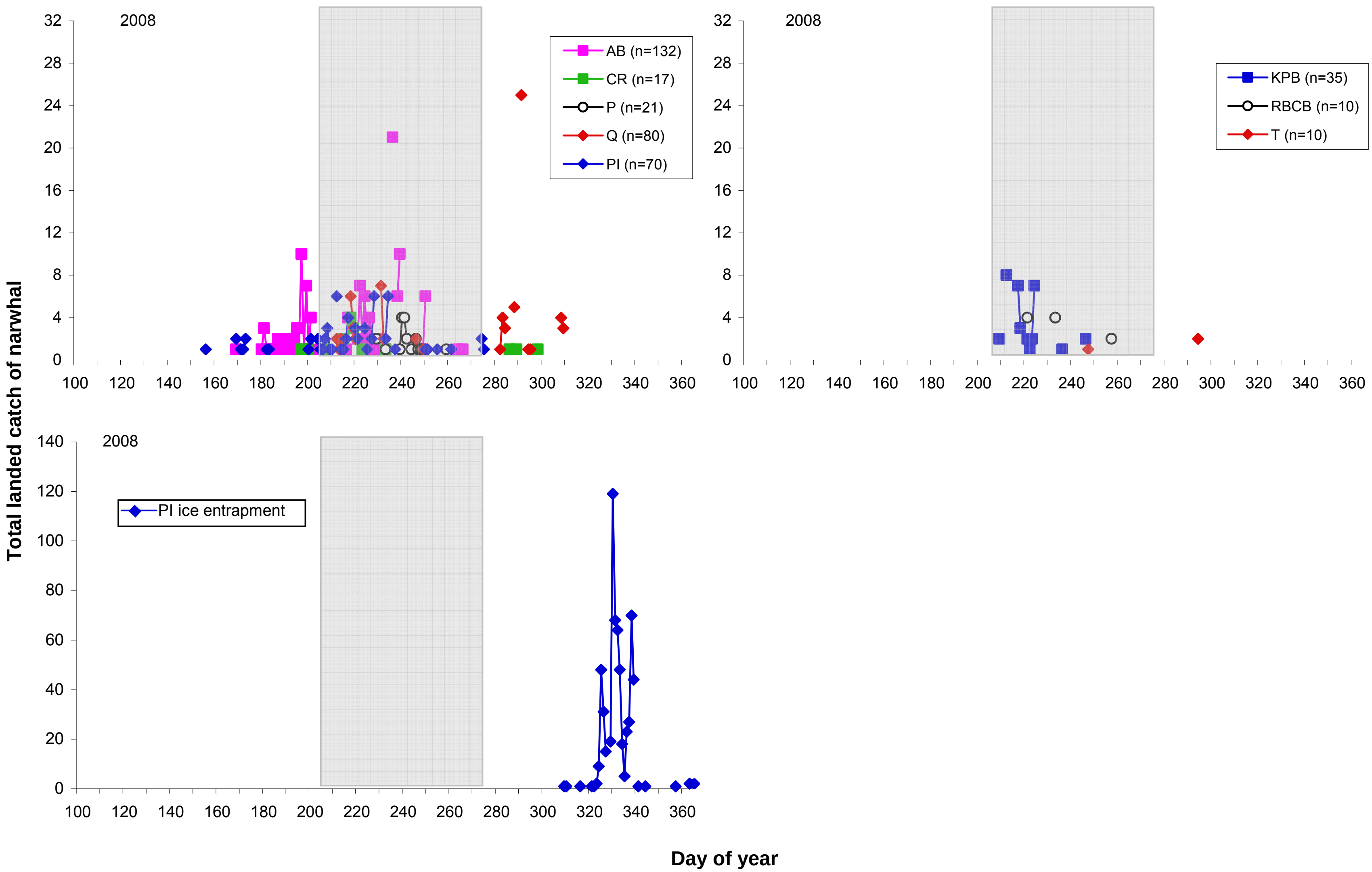


Fig. 4. Seasonal trends in community narwhal harvests from 2006-2010. Spring = < day of year 205; summer = day of year 205-274; fall = > day of year 274.



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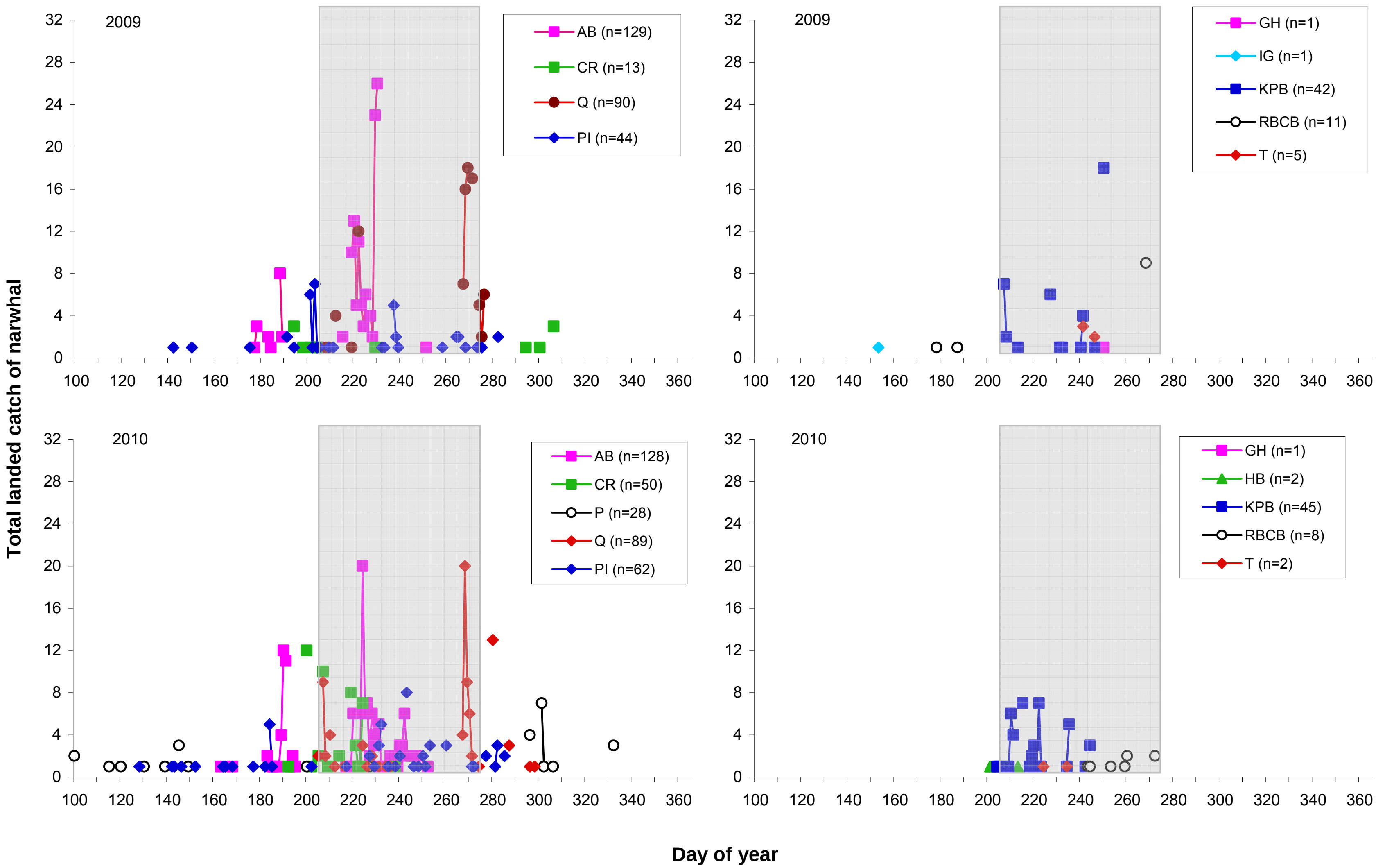

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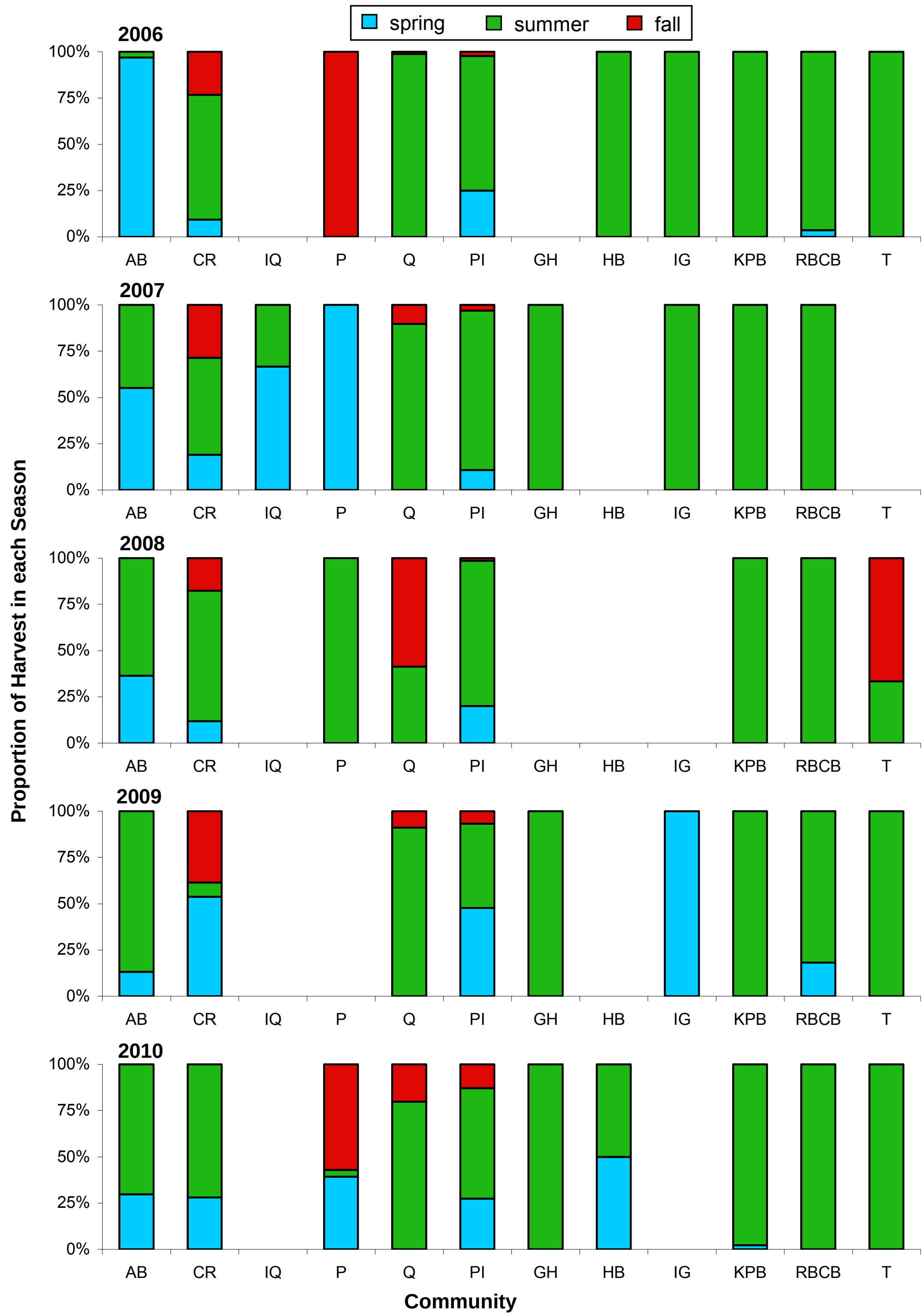


Fig. 5. Percent of annual narwhal harvests in spring, summer and fall in each community from 2006-2010. Spring = < day of year 205; summer= day of year 205-274; fall = > day of year 274.

Attribution Model Results

Model inputs and results for years (2006-2010) are included in Tables 4 and 5, respectively. Results demonstrate that in all years narwhal catches were sustainable (TALC-TC >0). If the unusual mortality due to the 2008 ice entrapment in Pond Inlet was included in the model as "harvest" (rather than appropriately as natural mortality), then the Admiralty Inlet and Eclipse Sound catches were not sustainable in 2008.

Table 4. Annual community attribution model inputs for 2006-2010.

Model Inputs:		2006	2007	2008	2008*	2009	2010
1 (W)		136	51	48	48	60	58
2 (Pg&Iq)		1	4	21	21	0	28
3 (AB summer proportion)		0.03	0.45	0.64	0.64	0.87	0.70
4 (PI summer proportion)		0.73	0.86	0.79	0.08	0.45	0.60
5 (CR summer proportion)		0.67	0.52	0.71	0.71	0.08	0.72
6 (Q summer proportion)		0.99	0.90	0.41	0.41	0.91	0.80
7 (community total catches)	AB:	130	127	132	132	129	128
	PI:	88	65	70	692	44	62
	CR:	43	42	17	17	13	50
	Q:	85	88	80	80	90	89

* 2008 harvest including the narwhal entrapment in PI

Table 5. Remainders of the stock TALCs for 2006-2010.

Stock	2006	2007	2008	2008*	2009	2010	mean **
SI	315	438	450	113	450	440	419
AI	191	147	108	-26	104	107	131
ES	128	146	134	-16	197	158	152
EB	6	14	62	62	35	2	24
Total	639	745	754	132	786	707	726

* 2008 harvest including the narwhal entrapment in PI

** 2006-2010 mean not including the 2008 narwhal entrapment in PI

To assess the reliability of tag returns, the number of tags allocated to each community that were confirmed to be either returned used or unused were calculated, with the remainder being "fate unknown" (Table 6). Given the relatively high number of unknown tag fates in some communities in some years (e.g. 39 unknown fate tags in Pangnirtung in 2007), the model was re-run for each year using revised community catches assuming that fate-unknown tags were actually used but lost (Table 7). The same summer proportions as in the original runs of the model were assumed. Model results did not indicate any substantial change in sustainability (Table 8).

Table 6. Number of "fate unknown" narwhal tags for each community in each year.

Community	2006	2007	2008	2008*	2009	2010
Arctic Bay	0	0	0	0	0	0
Clyde River	1	0	0	0	0	0
Gjoa Haven	0	4	0	0	4	0
Hall Beach	2	0	0	0	0	0
Igloolik	0	0	0	0	0	0
Iqaluit	0	0	11	11	0	0
Kugaaruk Pelley Bay	0	0	0	0	0	0
Pangnirtung	1	39	5	5	0	0
Pond Inlet	0	3	2	6	0	0
Qikiqtarjuaq	0	0	0	0	0	0
Resolute Bay/Creswell Bay	0	0	0	0	0	0
Taloyoak	0	0	0	0	0	2
Total	**4**	**46**	**18**	**22**	**4**	**2**

* 2008 harvest including the narwhal entrapment in PI

Table 7. Annual community attribution model inputs for 2006-2010, assuming that “unknown fate” tags were actually used.

Model Inputs:		2006	2007	2008	2008*	2009	2010
1 (W)		138	55	48	48	64	60
2 (Pg&Iq)		1	43	37	37	0	28
3 (AB summer proportion)		0.03	0.45	0.64	0.64	0.87	0.70
4 (PI summer proportion)		0.73	0.86	0.79	0.08	0.45	0.60
5 (CR summer proportion)		0.67	0.52	0.71	0.71	0.08	0.72
6 (Q summer proportion)		0.99	0.90	0.41	0.41	0.91	0.80
7 (community total catches)	AB:	130	127	132	132	129	128
	PI:	88	68	72	698	44	62
	CR:	44	42	17	17	13	50
	Q:	86	88	80	80	90	89

* 2008 harvest including the narwhal entrapment in PI

Table 8. Community attribution model results for 2006-2010, adjusted for unknown tags.

Stock	2006	2007	2008	2008*	2009	2010	mean **
SI	313	434	450	110	446	438	416
AI	191	132	102	-34	104	107	127
ES	128	127	126	-25	197	158	147
EB	4	6	59	59	35	2	21
Total	635	699	736	110	782	705	711

* 2008 harvest including the narwhal entrapment in PI

** 2006-2010 mean not including the 2008 narwhal entrapment in PI

Sensitivity Analysis Results

A. Sensitivity to assumption of proportional stock sizes

The results presented previously in Tables 4 and 8 are based on the assumption that non-summer catches are taken in the stock mixtures in proportion to the relative size of stocks to the total number of animals in stock mixtures. Figures 6 and 7 illustrate the moderate and higher risks associated with this assumption for all years. In both sets of sensitivity analyses, results demonstrate that minimal risk is associated with the harvests of all stocks in 2006, 2007, 2008, and 2009. In 2010, results of both analyses show a ~30% probability of exceeding the stock TALC for the East Baffin stock. However, if the East Baffin harvest was reduced to, for example, 80% of the observed value, the risks of overexploiting that stock would be negligible. Note that the results are similar in the moderate and extreme risk scenarios, likely owing to the robustness of the Somerset Island stock.

Both sensitivity models were also re-run including the narwhals harvested during the Pond Inlet ice entrapment in November, 2008 (Fig. 8a, b). In the first, moderate risk version of the sensitivity analysis, results demonstrate much higher risks of exceeding the stock TALC for SI, and particularly AI, and ES, although the risk for EB remains low. In the second, higher risk version, results demonstrate much higher risk of exceeding stocks TALCs for AI, and ES, although risks for SI and EB remain low.

B. Sensitivity to assumption of separate Admiralty Inlet and Eclipse Sound stocks

To evaluate the sensitivity of the results to the assumption of separate summering stocks for Admiralty Inlet and Eclipse Sound, the attribution model was revised to treat these two summering aggregations as one stock. Model inputs are the same as shown in Table 3. Revised model results for years (2006-2010) are included in Table 9. Results do not demonstrate a substantial departure from those presented in Table 5; narwhal catches in all years were sustainable (TALC-TC >0), with only slightly negative results for EB in 2010. Again, if the unusual mortality due to the 2008 ice entrapment in Pond Inlet was included in the model as “harvest” (rather than natural mortality), then the combined Admiralty Inlet and Eclipse Sound catches were not sustainable in 2008.

Table 9. Remainders of the stock TALCs for 2006-2010, assuming that AI and ES are one stock.

Stock	2006	2007	2008	2008*	2009	2010	mean **
SI	295	428	442	22	444	431	408
AI & ES	127	94	45	-157	96	67	86
EB	4	11	54	54	33	-4	19
Total	426	532	541	-81	573	494	513

* 2008 harvest including the narwhal entrapment in PI

** 2006-2010 mean not including the 2008 narwhal entrapment in PI

The results presented in Table 9 are based on the unlikely assumption the AI and ES summering aggregations are one stock. Figures 9 and 10 illustrate the moderate and higher risks associated with this assumption for all years. In the moderate risk scenario, results demonstrate that minimal risk is associated with the harvests of all stocks in 2006, 2007, 2008, and 2009. In 2010, results show a ~60% probability of exceeding the stock TALC for the East Baffin stock. However, if the East Baffin harvest was reduced to, for example, 80% of the observed value, the risks of overexploiting that stock would be negligible.

In the extreme risk scenario, results demonstrate that minimal risk is associated with the harvests of all stocks in 2006, 2007, and 2009. In 2008, results show a 10% probability of exceeding the stock TALC for the Admiralty Inlet/Eclipse Sound stock. However, if the Admiralty Inlet/Eclipse Sound harvest was reduced to, for example, 80% of the observed value, the risks of overexploiting that stock would be negligible. In 2010, results show a ~60% probability of exceeding the stock TALC for the East Baffin stock. However, if the East Baffin harvest was reduced to, for example, 80% of the observed value, the risks of overexploiting that stock would be negligible.

Both sensitivity models were also re-run including the narwhals harvested during the Pond Inlet ice entrapment in November, 2008 (Fig. 11a, b). In the first, moderate risk version of the sensitivity analysis, results demonstrate much higher risks of exceeding stock TALC for SI, and particularly the AI/ES stock, although the risk for EB remains low. If the SI harvest was reduced to 80% of the observed value, the risks of overexploiting that stock would be negligible. If the AI/ES stock was reduced to 50% of the observed value, the risks of overexploiting that stock would be negligible.

In the second, higher risk version, results demonstrate relatively low risks of exceeding stock TALC for SI, and negligible risks for EB. If the SI harvest was reduced to 80% of the observed value, the risks of overexploiting that stock would be negligible. However, the risk of exceeding stock TALC for the AI/ES stock is high. Even if the AI/ES stock was reduced to 50% of the observed value, the risks of overexploiting that stock would remain high at ~80%.

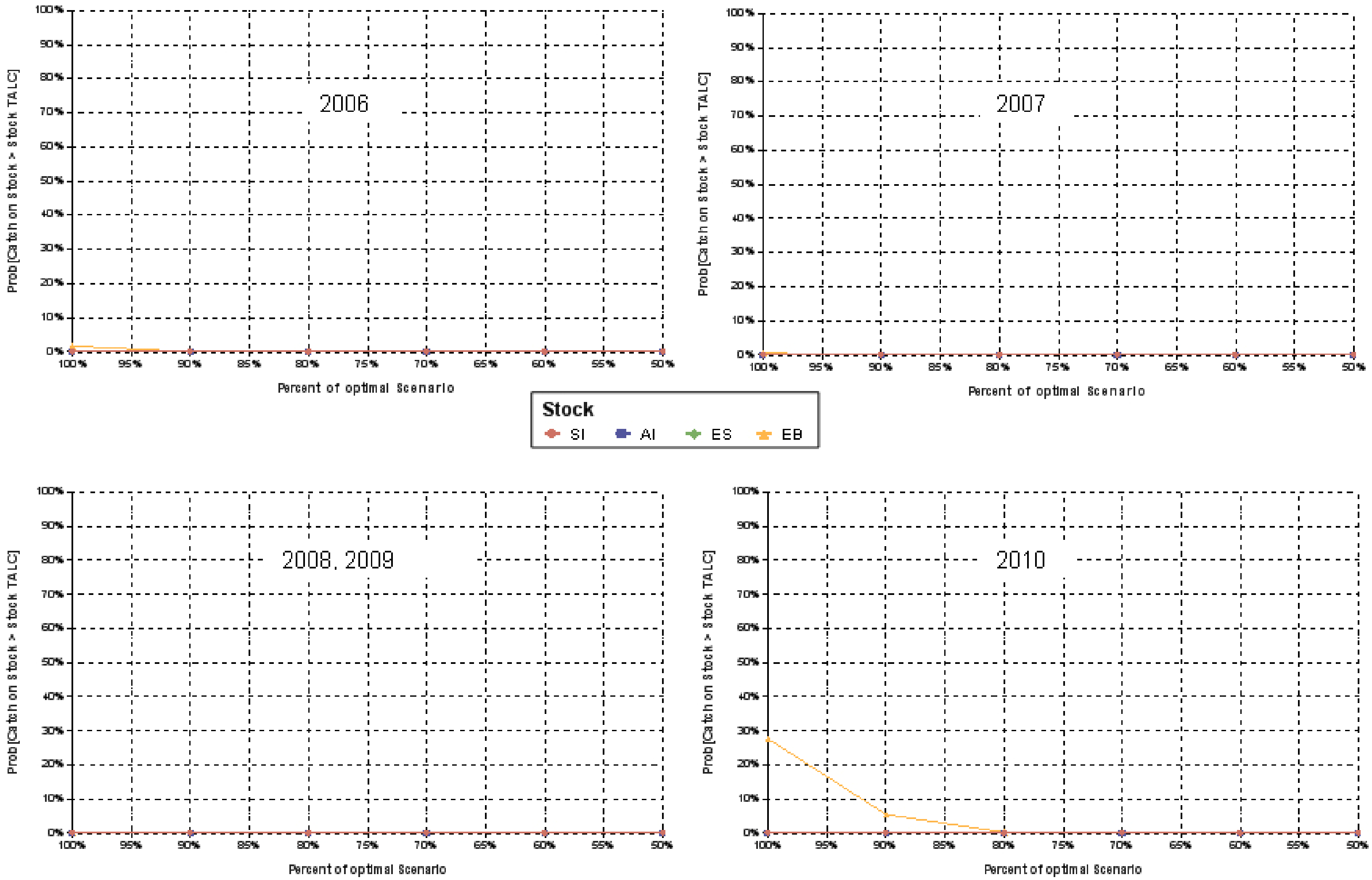


Fig. 6. Probability of exceeding stock TALCs in each year if the catches are reduced from 100% to 50% of their original (100%) values, assuming annual observed summer catch proportions for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq. Stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. Note that the 2008 data does not include the narwhals harvested in the Pond Inlet ice entrapment.

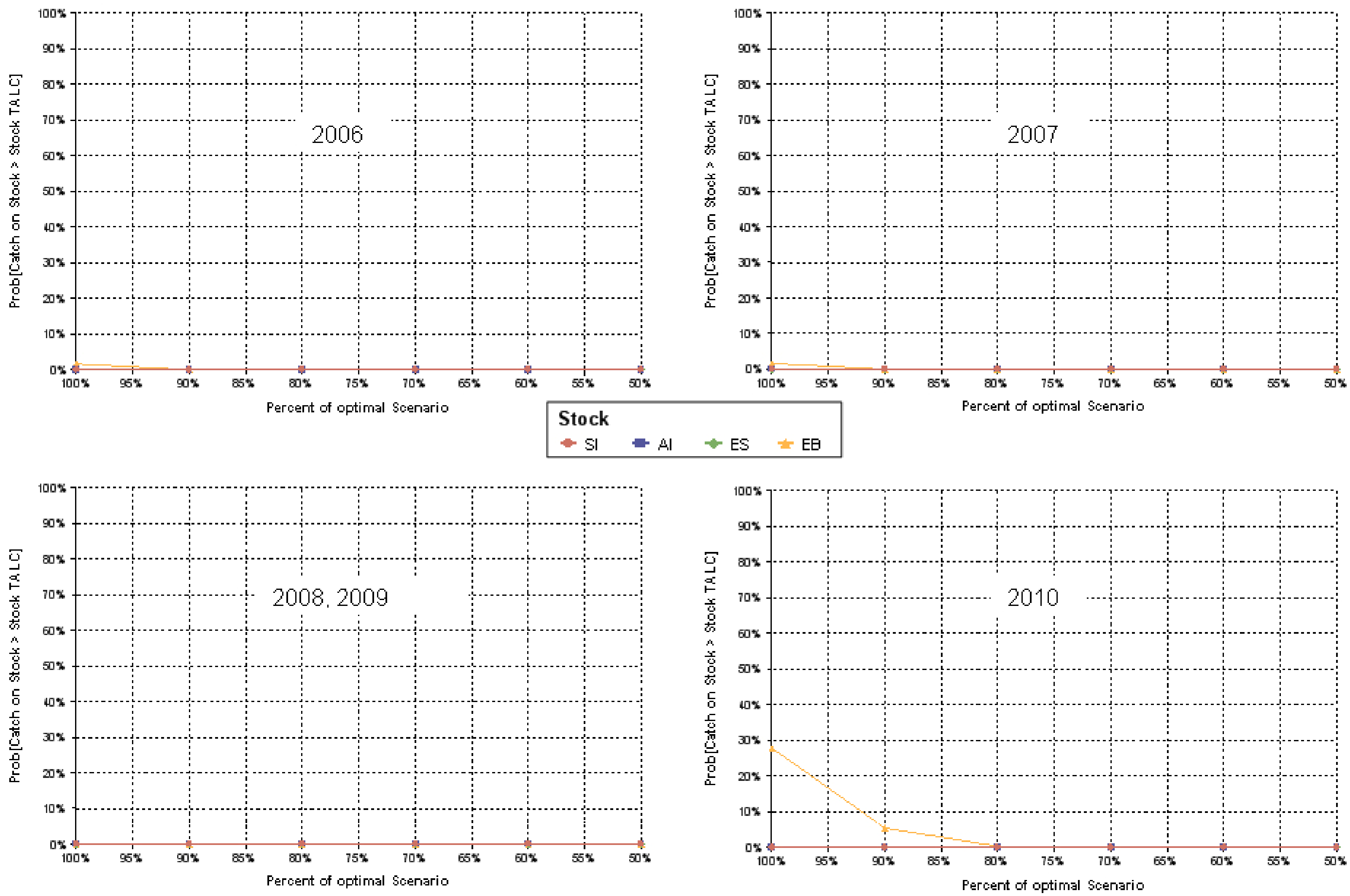


Fig. 7. Probability of exceeding stock TALCs in each year if the catches are reduced from 100% to 50% of their original (100%) values, assuming annual observed summer catch proportions for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq. Except for the SI stock, stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. The SI stock proportion in the Western non summer mixture is a normalized gamma (1, 0.2) distribution. Note that the 2008 data does not include the narwhals harvested in the Pond Inlet ice entrapment.

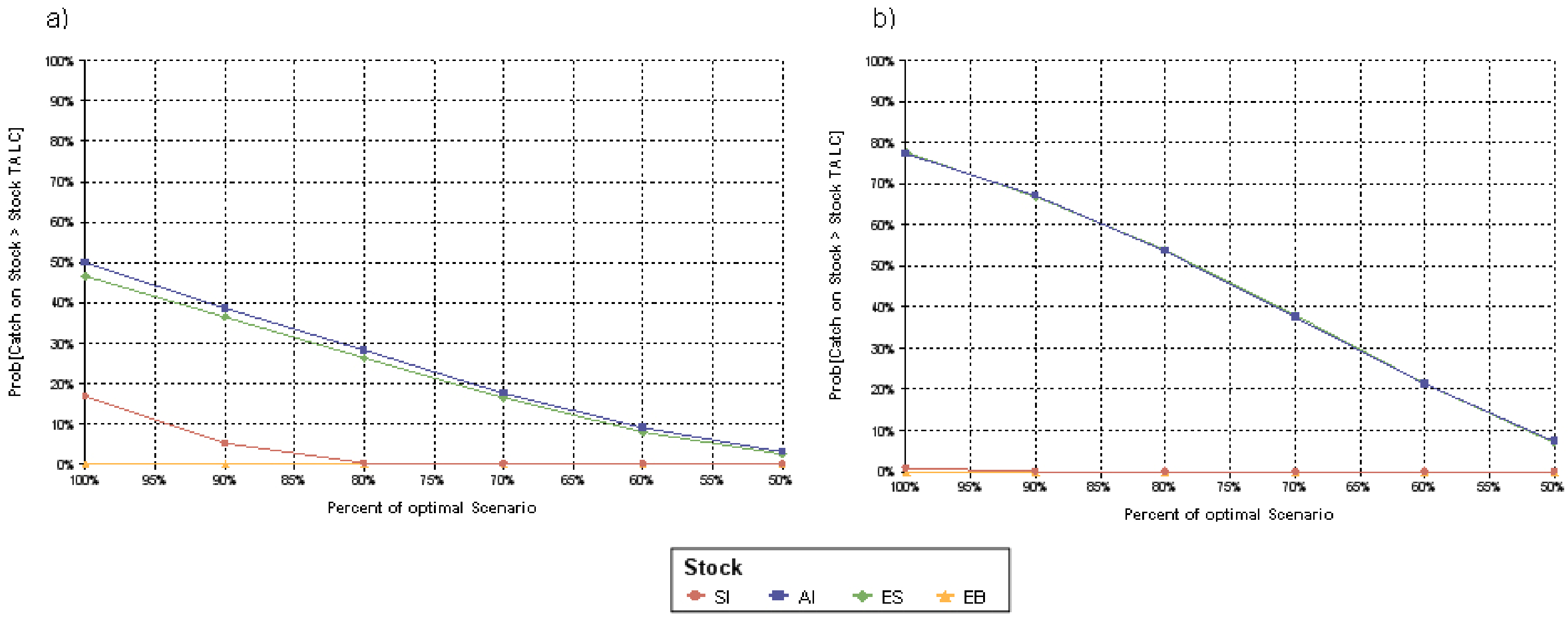


Fig. 8. Probability of exceeding stock TALCs in 2008, including the narwhals harvested in the Pond Inlet ice entrapment, if the catches are reduced from 100% to 50% of their original (100%) values, assuming annual observed summer catch proportions for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq. In (a) stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. In (b), except for the SI stock, stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. The SI stock proportion in the Western non-summer mixture is a normalized gamma (1,0.2) distribution.

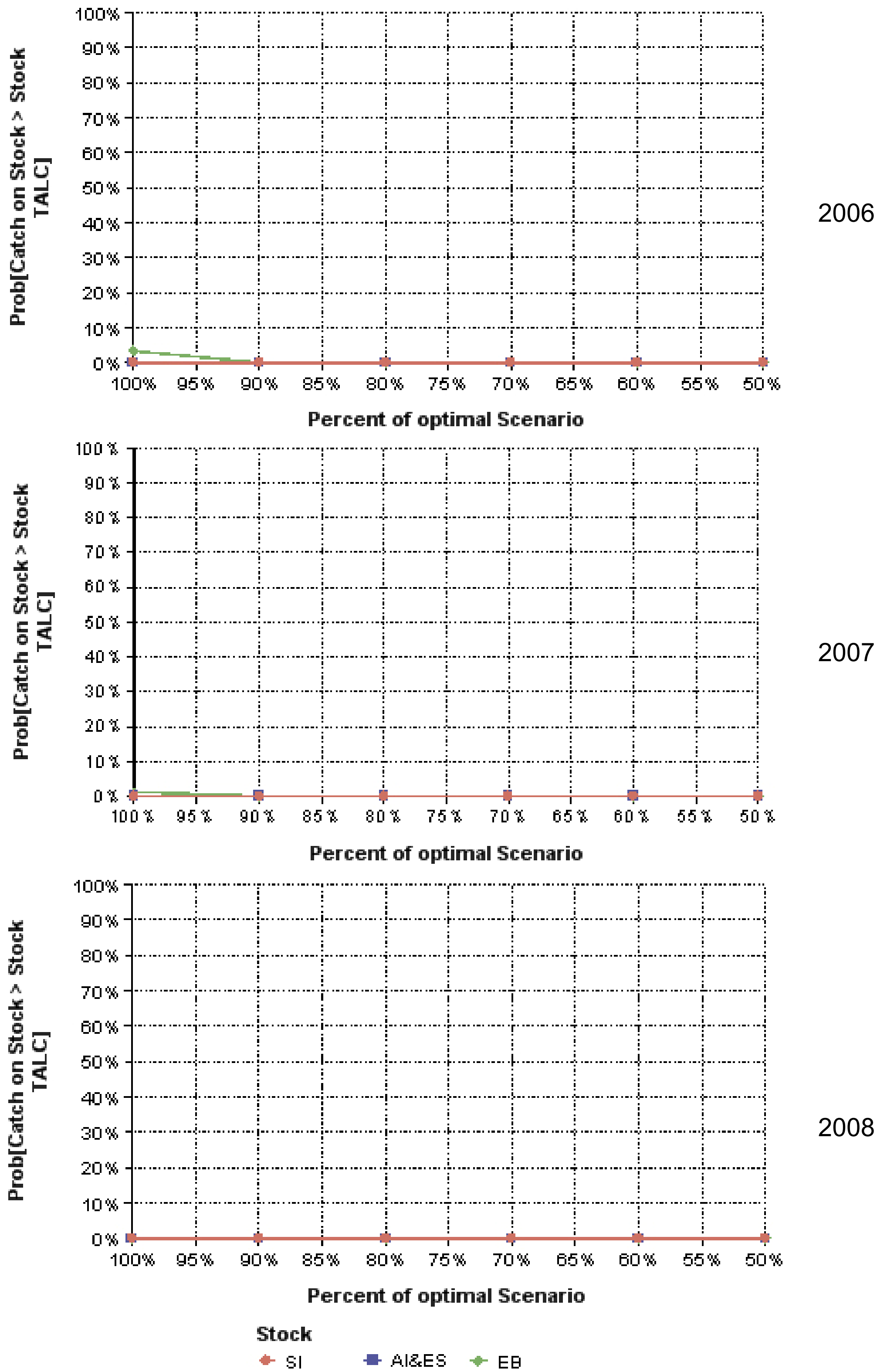
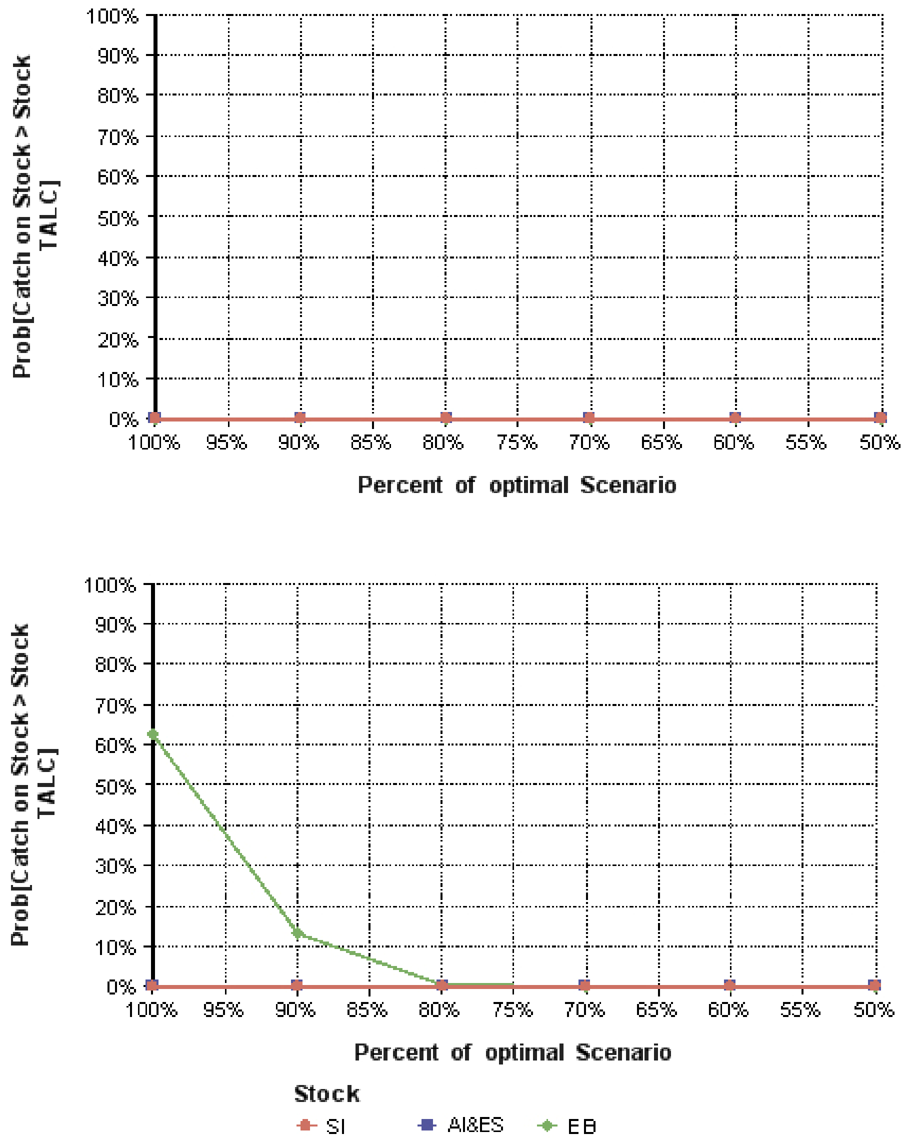


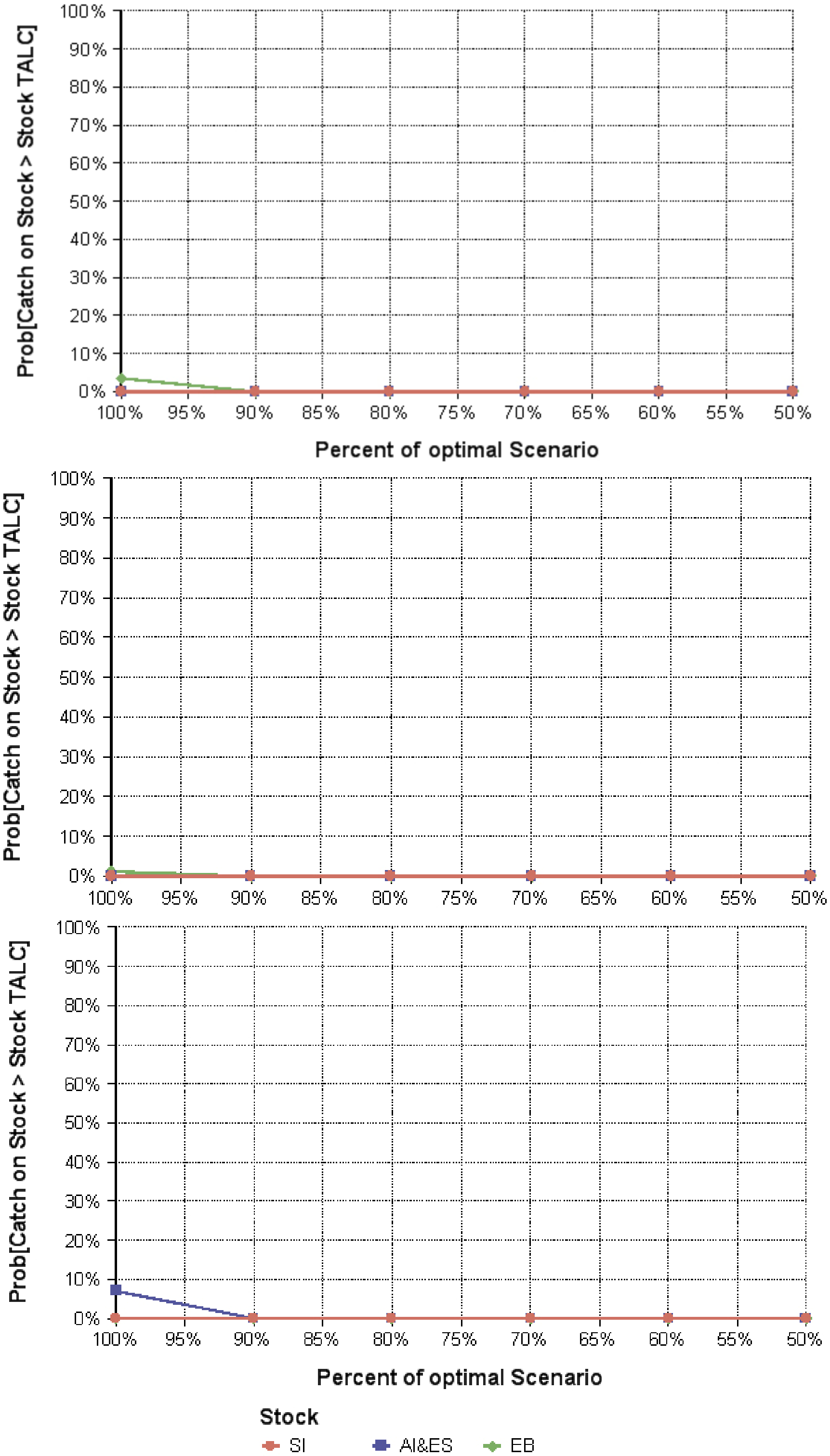
Fig. 9. Assuming Admiralty Inlet and Eclipse Sound are one stock, the probability of exceeding stock TALCs in each year if the catches are reduced from 100% to 50% of their original (100%) values, assuming annual observed summer catch proportions for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq. Stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. Note that the 2008 data does not include the narwhals harvested in the Pond Inlet ice entrapment.



2009

2010

Fig 9. Continued.

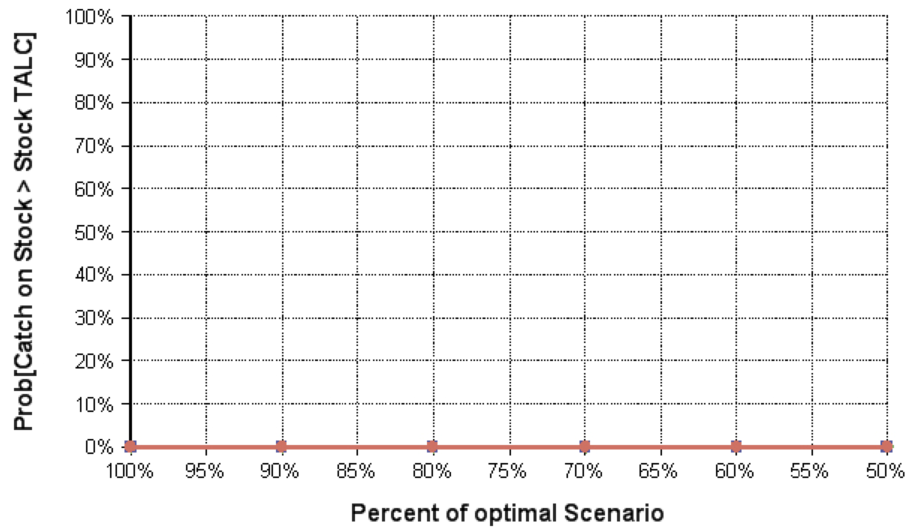


2006

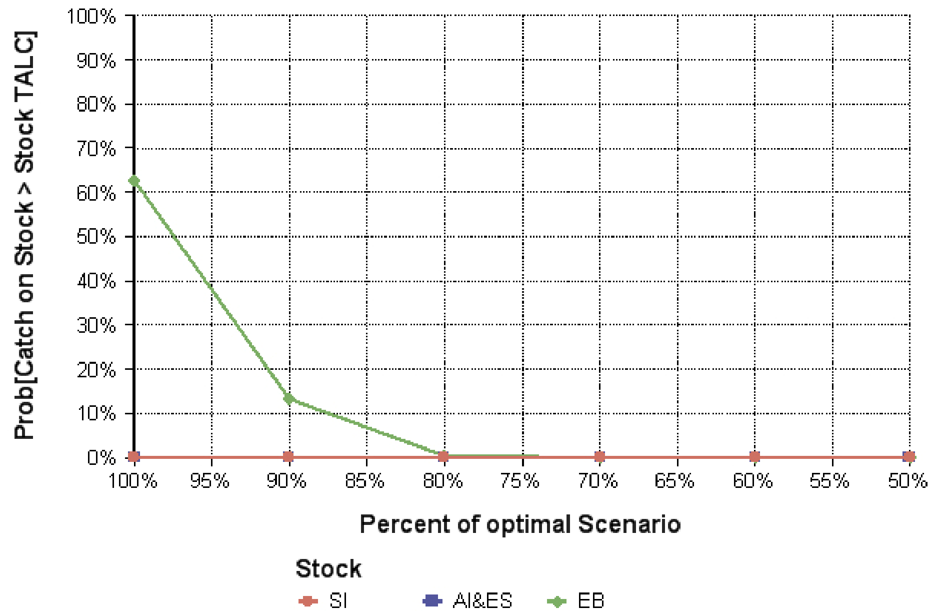
2007

2008

Fig. 10. Assuming Admiralty Inlet and Eclipse Sound are one stock, the probability of exceeding stock TALCs if the catches are reduced from 100% to 50% of their original (100%) values, assuming annual observed summer catch proportions for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq. In (a) stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. In (b), except for the SI stock, stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. The SI stock proportion in the Western non-summer mixture is a normalized gamma (1, 0.2) distribution.



2009



2010

Fig. 10 continued.

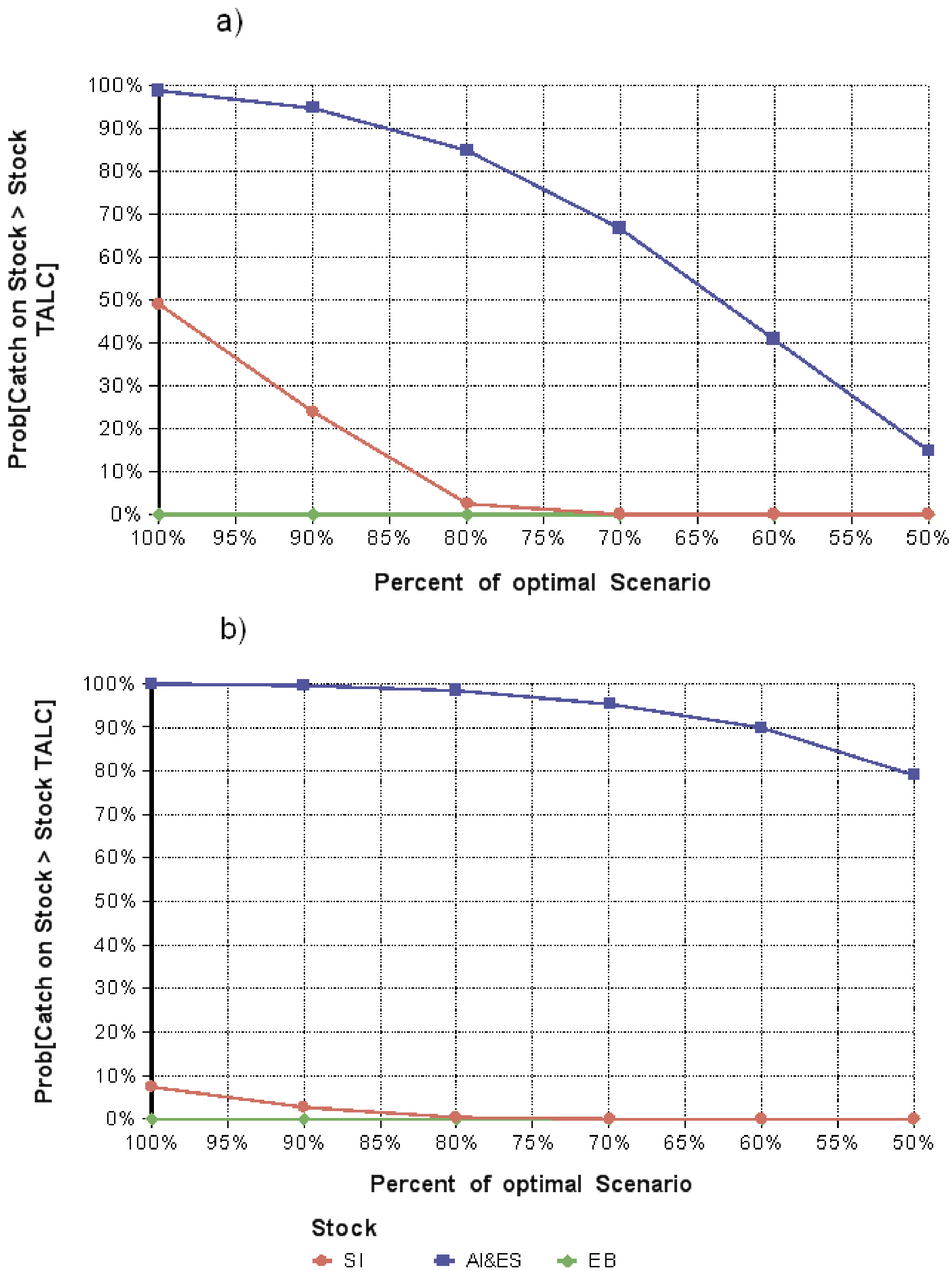


Fig. 11. Assuming Admiralty Inlet and Eclipse Sound are one stock, the probability of exceeding stock TALCs in 2008, including the narwhals harvested in the Pond Inlet ice entrapment, if the catches are reduced from 100% to 50% of their original (100%) values, assuming annual observed summer catch proportions for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq. In (a) stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. In (b), except for the SI stock, stock proportions are set as normalized lognormals with stock proportions calculated from mean stock sizes in each non-summer stock mixture. The SI stock proportion in the Western non-summer mixture is a normalized gamma (1, 0.2) distribution.

Sources of Uncertainty

One source of uncertainly is the tag data used to estimate the 2006-2010 narwhal harvest data. Although the annual tag databases were verified and proof read in 2011 (P. Hall, pers. comm.) against the paper tag records, it remains possible (although unlikely) that some of the individual harvest dates recorded are incorrect. However, even if this were the case, the errors associated with the dates would have to be numerous and relatively large to have significant impact on the estimate of proportion of the harvest occurring in summer.

All narwhal stocks have not been surveyed in one year, and the Greenland portion of the population has not been included in the estimates of population abundance. This may increase uncertainty in the accuracy of the TALCs. In addition, most TALC calculations are based on dated surveys (see Table 1), with the exception of Admiralty Inlet, which was surveyed in 2010.

The 2010 survey of Admiralty Inlet (DFO 2012b) resulted in a much higher estimate of the summering population than the previous estimate. The 2010 population estimate was used in the construction of the model; there may be concern regarding whether the 2010 estimate should be used in the analysis of the 2006-2009 data. However, using the 2003 Admiralty Inlet estimate may not change the results substantially given the size of the SI stock and its relative contribution to the overall Baffin Bay harvest.

Although the Somerset Island and East Baffin Island stocks are considered as individual stock units, because they cover large geographic areas, it is possible that they may have further sub-stock structuring which may influence the model inputs and results.

Although the TALCs have been corrected for loss rates (LRC = 1.28, see Richard 2011), loss rates that are specific to each community or season are not available. Loss rates may vary depending on several factors, including the conditions of the hunt and the experience of hunters.

Some of our current understanding of stock structure in narwhals is drawn from data on similar species such as belugas. For example, depleted Eastern Hudson Bay belugas are harvested in higher numbers than would be predicted from their relative proportion in the population (Doniol-Valcroze et al. 2010). However, narwhals may differ from belugas in terms of the appropriateness of using proportionality. For example, the Lancaster Sound migration corridor used by narwhals is narrower than Hudson Strait where belugas migrate. Also, tagged Western Hudson Bay belugas migrated further north of Nunavik than their Eastern counterparts which migrate close to Nunavik shores (P. Richard, pers. comm.).

There is uncertainty associated with the proportion of each stock that is available to each community during the spring and fall. The proportion of animals belonging to any particular stock in the non-summer community harvest is unknown, but it is assumed to be proportional to the size of each stock relative to the total number of animals in the mixture of stocks. For example, the SI stock migrates into Baffin Bay in the fall, but it is not known what proportion of that stock is available to hunters along the migration route or for what duration. Although SI is the largest stock, it is possible that only a fraction is actually available to hunters in spring and fall. As described above, sensitivity of the modeling analyses to this assumption was evaluated using risk modeling.

Conclusions

The results indicate that narwhal hunts by communites from 2006-2010 were sustainable (with the exception of Admiralty Inlet and Eclipse Sound in 2008 and only when the humane harvest due to the ice entrapment in Pond Inlet was included). Although ice entrapment harvests are uncommon and losses due to ice entrapments would normally be considered as natural mortality, model runs incorporating the 2008 ice entrapment in Pond Inlet illustrate the potential impact that high “natural mortality” events may have on the sustainability of the overall harvest. Although such events are rare historically, they could increase in frequency in the future as a result of ecological changes brought about by climate change (Laidre and Heide-Jørgensen, 2005). The retrospective analysis conducted demonstrates overall stock robustness to the current frequency of entrapment events.

Contributors

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