ADVICE ON AN ALLOCATION MODEL FOR LANDED CATCHES FROM BAFFIN BAY NARWHAL STOCKS

Narwhal *Monodon monoceros*
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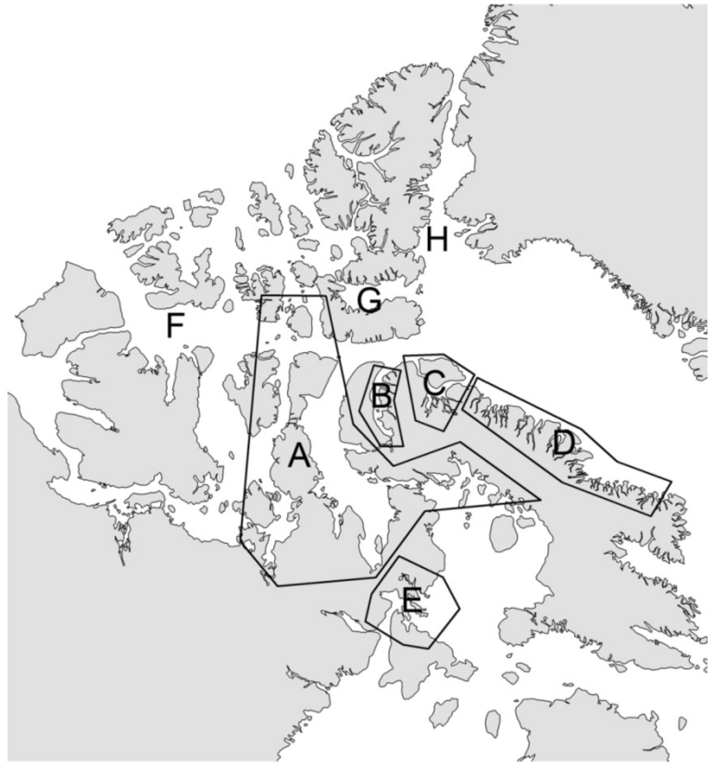

Figure 1. Approximate boundaries of the Canadian summering aggregations of narwhals which represent distinct stocks (i.e., management units). Four stocks belong to the Baffin Bay population: A - Somerset Island, B - Admiralty Inlet, C - Eclipse Sound and D - East Baffin Island. The Northern Hudson Bay population (E) and other areas where narwhals are known to occur (F, G and H) are not included in the allocation model.

Context

The Baffin Bay narwhal population is composed of at least four separate stocks on the basis of summering aggregations. Animals from one summering stock may be harvested by communities located near their summering aggregations as well as by more distant communities during spring and fall migrations. Narwhals in the migratory herds cannot be differentiated, and the proportion of different management units represented in spring and fall community catches is unknown. Therefore, total hunting pressure on individual stocks cannot be assessed directly. Fisheries and Oceans Canada (DFO) Ecosystems and Fisheries Management Sector asked for advice on how best to determine community allocations so that harvests from each of the summering stocks are consistent with their sustainable catch recommendations. To that end, a community landed catch allocation tool was developed to facilitate the process of apportioning narwhal catch limits to each of the Nunavut communities that hunt from Baffin Bay narwhal stocks. This science advisory report presents information and advice on the allocation tool.

SUMMARY

- A community landed catch allocation tool for Baffin Bay narwhals in Canadian waters was developed using an allocation model and risk analysis. It was structured around a spatial and temporal model of narwhal mixtures based on available information on narwhal seasonal distribution.
- Co-managers can explore the impact of allocation decisions by varying the amounts of landed catches by communities at both ends of the range of the four stocks and setting the proportions of the catch that are to be taken in the summer season. A structured optimization version and a simpler, iterative version of the allocation model are available.
- The allocation tool produces possible solutions that maximize community catches, particularly for those with large historic narwhal catches, while minimizing the risk of over-exploitation of any one stock. Four sets of scenarios were run to illustrate the types of results that can be produced.
- As the proportion of animals belonging to any particular stock in the non-summer community harvest is unknown, the model assumes 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.
- Sensitivity analyses, run to test this assumption, resulted in a medium to high risk of exceeding Total Allowable Landed Catches (TALCs) for Admiralty Inlet, Eclipse Sound and East Baffin Island if the entire optimized catches are taken.
- In general, reducing the community allocations to 80-90% of the optimized catches significantly lowered the risk of exceeding a stock’s TALC.

BACKGROUND

The Baffin Bay narwhal population is composed of at least four summering aggregations in Canadian waters which, for management purposes, are considered separate stocks (Richard 2010). They are harvested by communities located near their summering aggregations as well as by more distant communities during their spring and fall migrations. As narwhals cannot be differentiated by stock in their migratory herds, the proportion of different management units represented in spring and fall community catches is unknown, thus total hunting pressure on individual stocks cannot be assessed directly. A community landed catch allocation tool was developed by DFO Science to help co-managers decide on how best to allocate TALCs for the four Baffin Bay summering stocks, given that part of the catches for several communities comes from non-summer mixed stocks of narwhals.

The allocation tool is meant to be easy to use and to allow co-managers the opportunity to explore the impact of allocation decisions on each of the communities that harvest from the four stocks. It is based on a spatial model of the source and degree of stock mixtures that are hunted and produces 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. The allocation tool does not address hunting by Grise Fiord because the relationship of the narwhals they harvest to the four known Baffin Bay stocks is unknown. It also does not include Northern Hudson Bay narwhals because those whales are managed as a separate population.

ANALYSIS

Spatial Model of Narwhal Seasonal Distribution

The Canadian portion of the Baffin Bay narwhal population is composed of four known summering stocks: Somerset Island, Admiralty Inlet, Eclipse Sound and East Baffin (Figure 1). These stocks are thought to be relatively sedentary in summer and are hunted in their summer range by local communities. The Somerset Island stock is largest in size and has a wider summer distribution than all the other summering stocks. The communities of Resolute Bay, Gjoa Haven, Taloyoak, Kugaaruk, Igloolik and Hall Beach (the “Western Communities”) most likely take narwhals only in summer, from the Somerset Island stock, although in the past Hall Beach hunters have also travelled south to take narwhals from the Northern Hudson Bay population. Harvest from the Somerset Island stock by the Western Communities is referred to as the “Western Annual Catch” in this document (Figure 2).

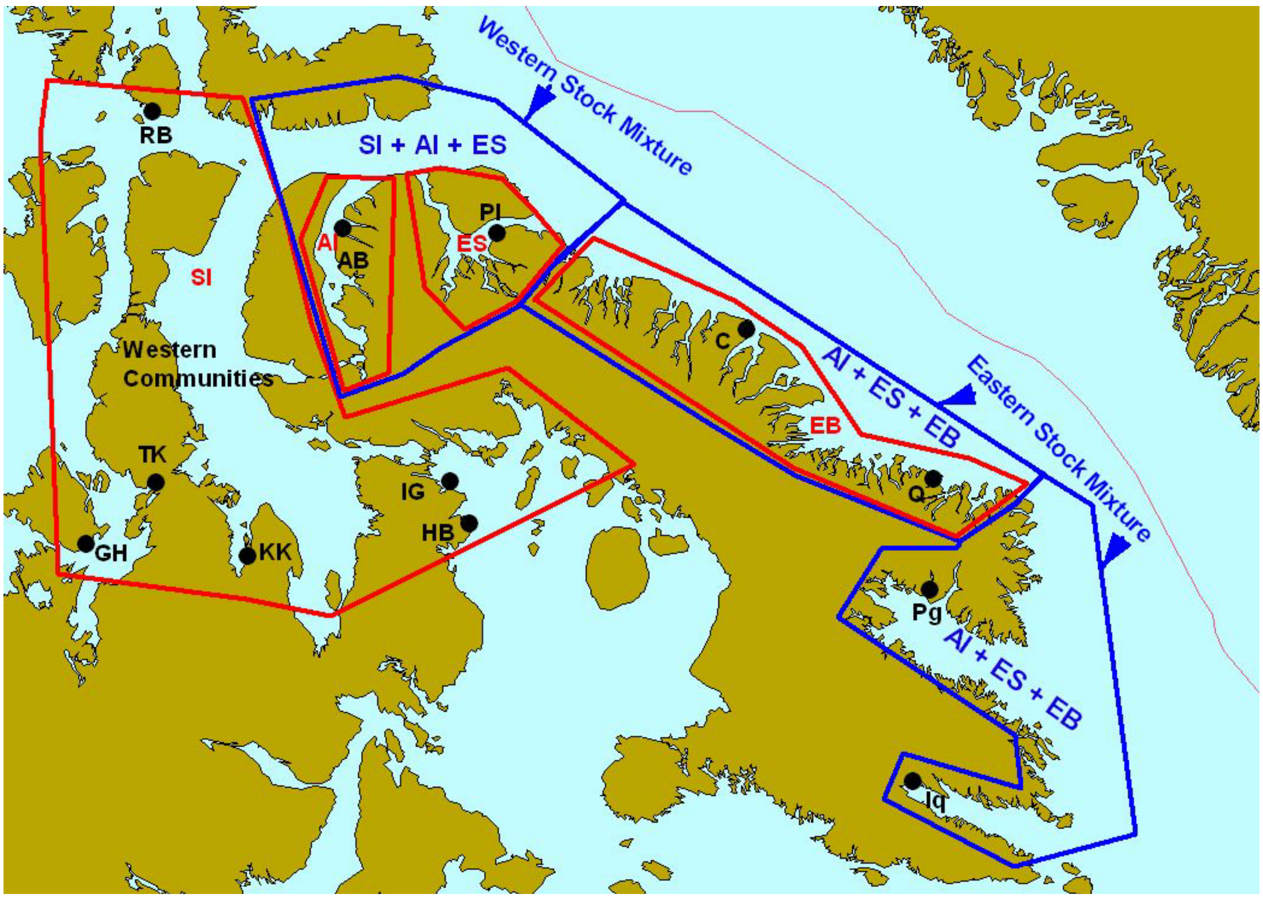

Figure 2. Schematic representation of the summering stocks discussed in the text (in red letters: SI: Somerset Island stock; AI: Admiralty Inlet stock; ES: Eclipse Sound stock; EB: East Baffin Island stock)and of non-summer stock mixtures (in blue letters). Communities that hunt the stocks are indicated 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) (Richard 2011).

In contrast to the Western Communities, the communities of Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq on northern and eastern Baffin Island take substantial numbers of narwhals in the fall, winter or spring seasons as well as in summer. Based on surveys and tracking studies it seems likely that Arctic Bay and Pond Inlet hunt a mixture of stocks composed of Somerset Island, Admiralty Inlet and Eclipse Sound stocks (the “Western Stock Mixture”) outside the summer open-water season. Clyde River and Qikiqtarjuaq hunt from a mixture of Admiralty Inlet, Eclipse Sound and East Baffin Island stocks (the “Eastern Stock Mixture”) during the non-summer seasons. Tracking indicates that animals from the Somerset Island stock move offshore to the center and east side of Baffin Bay in fall therefore it is probably not part of the “Eastern Stock Mixture” (Appendix 1).

The two southeast Baffin Island communities, Pangnirtung and rarely Iqaluit, take narwhals from the Eastern Stock Mixture in spring or fall. Pangnirtung hunters also occasionally encounter narwhals in Cumberland Sound in summer.

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. Sensitivity of the modelling results to this assumption was evaluated using risk modelling.

Model Inputs

The allocation tool has two parts: an allocation step and a risk analysis step. The first step involves determining model inputs and then running the model to allocate catches. Some inputs to the model are decision variables. Proportions of the hunt (between 0% and 100%) taken in summer by a community or set of communities (Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq) is entered into the model as a decision variable rather than being mathematically optimized. This is because hunts conducted by those communities during non-summer seasons are affected by logistical constraints (e.g., how long the spring floe edge hunt can reasonably last or how many animals can be taken in fall weather). The summer proportions of the hunt for these four communities should be fixed prior to the hunting season by co-managers based on consultation with local hunters. It will be possible to determine the dates surrounding the open-water period by incorporating local conditions on an annual basis. The size of the Western Annual Catch is also entered into the model as a decision variable because the Western Annual Catch is relatively small and primarily from the largest stock (i.e., Somerset Island stock), and supports non-summer hunts for Arctic Bay and Pond Inlet. Finally, the Pangnirtung and Iqaluit hunts produce small catches so their landed catch is combined. The size of this combined catch also enters the model as a decision variable.

Once the decision parameters are set, the allocation tool can be run to optimize the landed catch by the Nunavut communities that have historically relied most on narwhal hunting for their subsistence and economic well-being (i.e., Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq). Depending on the version of the allocation tool, either linear optimization or a stepwise approach is used to solve the model by finding the optimal division of annual landed catches for those communities without the TALC being exceeded for any of the four stocks.

Description of the Optimization Model

The model calculates the total catch (TC) from each stock (i.e., summer catch + non-summer catch) and subtracts that from the TALC. The optimization is constrained by limiting solutions to positive or zero values of TALC-TC (i.e., equal to or greater than zero) while minimizing the remainders for stock TALCs. The summer catch from each stock is calculated by multiplying the annual narwhal catch for a community by the proportion taken in summer (SP) and then summing for all communities that hunt from the stock. The non-summer catch from each stock is calculated by multiplying the proportion of catch taken outside of summer months (i.e., 1-SP) for a community by the non-summer stock proportion in the mixture and the annual catch by community, then summing for all communities that hunt from the stock. (See Richard 2011 for a full description of the optimization model.)

The modeling was developed using the software Analytica 4.3 Professional with Optimizer (www.lumina.com). In the structured optimization version, the annual catch for both Clyde River and Qikiqtarjuaq was optimized as a set because the software was unable to optimize them separately without favouring one or the other communities. Hence a new parameter was introduced to allocate total catch between those two communities. For illustration purposes, the total catch was apportioned by 0.4 and 0.6 for Clyde River and Qikiqtarjuaq, respectively. Other ratios could be chosen by co-managers if they choose to use this structured optimization version of the allocation model. The simpler iterative versions of the allocation model and the sensitivity analyses treat the two communities separately.

Four sets of scenarios were run with the structured optimization version, using different proportions of summer catches for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq and a range of decisions on Western Annual Catches (100-500) and Pangnirtung-Iqaluit catches (20-80). The scenarios span the range of summer catch proportions from low (Table 1) to high (Table 2), including proportions modeled after tag returns from past decades (Romberg and Richard. DFO unpubl. data). The high summer catch proportions may be more realistic for the future, as climate change acts to shorten the season during which floe edge hunts for narwhals can be safely conducted, with a progressively earlier fast-ice melt.

In general, the results indicated that optimal landed catch levels for Arctic Bay, Pond Inlet and for Clyde River and Qikiqtarjuaq combined can be more than 138 and, under certain scenarios for some communities, could be in excess of 300. Varying the Pangnirtung-Iqaluit catch had a noticeable effect on the optimized catches, causing them to go down as the Pangnirtung-Iqaluit catch increases. In contrast, for most scenarios with low summer catch proportions (high non-summer proportions), only a small reduction in the optimized catches for Arctic Bay, Pond Inlet, and Clyde and Qikiqtarjuaq combined occurred when the Western Annual Catch was increased up to 400. This is because the relative size of the Somerset Island stock is large and the summer harvests small. However, when the Western Annual Catch was set to 500 or close to the TALC (i.e., 532; DFO 2012), the optimized results become unstable, having to choose between Arctic Bay or Pond Inlet to allocate the catch (Tables 1 and 2). The Somerset Island TALC was never fully used except when the Western Annual Catch was at 500 because the linear optimization stops when the remainder of the TALCs reaches less than 1 (note: shown as 0 or 1 because of rounding) for the smaller stocks. The full TALC of the Somerset Island stock cannot be allocated without risking an over-harvest of the smaller stocks that are in non-summer mixtures.

Sensitivity analysis

The optimization scenarios were 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 mean abundances for the Somerset Island, Admiralty Inlet, and Eclipse Sound stocks have been estimated at 45,358 narwhals, 18,049 narwhals and 20,225 narwhals, respectively (DFO 2012). The Admiralty Inlet mean stock size represents 22% of the Western Stock Mixture, therefore in the model it is assumed that 22% of the non-summer catch for the communities of Arctic Bay and Pond Inlet 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.

Table 1. Illustration of possible optimal annual catches for Arctic Bay, Pond Inlet, and Clyde River and Qikiqtarjuaq, assuming summer proportion of catch is respectively 0.50, 0.50, 0.50, 0.50, given specific annual catches for Resolute, Kitikmeot and N Foxe Basin communities, and for Pangnirtung-Iqaluit. The side panel gives the remainder of the TALC for each stock after the allocation tool maximizes the catch under the decision parameters. In this scenario, Clyde and Qikiqtarjuaq share their total annual catch in a 0.4 / 0.6 proportional allocation for illustration purposes.

Optimized total catch by communities or group of communities / **Remainder of stock TALCs**

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total	SI	AI	ES	EB
100	267	247	78	117	20	829	293	0	0	0
200	267	247	78	117	20	929	193	0	0	0
300	267	247	78	117	20	1029	93	0	0	0
400	242	244	78	117	20	1101	0	16	5	0
500	0	118	78	117	20	833	0	176	113	0

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total	SI	AI	ES	EB
100	259	238	75	112	40	824	297	0	0	1
200	259	238	75	112	40	924	197	0	0	1
300	259	238	75	112	40	1024	97	0	0	1
400	255	231	75	113	40	1114	0	3	5	0
500	0	118	75	113	40	846	0	170	106	0

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total	SI	AI	ES	EB
100	250	228	72	109	60	819	302	0	0	0
200	250	228	72	109	60	919	202	0	0	0
300	250	228	72	109	60	1019	102	0	0	0
400	250	228	72	109	60	1119	2	0	0	0
500	0	118	72	109	60	859	0	164	99	0

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total	SI	AI	ES	EB
100	242	219	69	104	80	814	307	0	0	1
200	242	219	69	104	80	914	207	0	0	1
300	242	219	69	104	80	1014	107	0	0	1
400	242	219	69	104	80	1114	7	0	0	1
500	0	118	70	104	80	872	0	158	92	0

Table 2. Illustration of possible optimal annual catches for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq, assuming summer proportion of catch is respectively 0.90, 0.90, 0.70, 0.70, given specific annual catches for Resolute, Kitikmeot and N Foxe Basin communities, and for Pangnirtung-Iqaluit. The side panel gives the remainder of the TALC for each stock after the allocation tool maximizes the catch under the decision parameters. In this scenario, Clyde and Qikiqtarjuaq share their total annual catch in a 0.4 / 0.6 proportional allocation for illustration purposes.

Optimized total catch by communities or group of communities

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total
100	220	218	62	92	20	712
200	220	218	62	92	20	812
300	220	218	62	92	20	912
400	220	218	62	92	20	1012
500	220	218	62	92	20	1112

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total
100	213	210	60	89	40	712
200	213	210	60	89	40	812
300	213	210	60	89	40	912
400	213	210	60	89	40	1012
500	213	210	60	89	40	1112

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total
100	206	202	57	86	60	711
200	206	202	57	86	60	811
300	206	202	57	86	60	911
400	206	202	57	86	60	1011
500	206	202	57	86	60	1111

Resolute, Kitikmeot & N Foxe Basin	Arctic Bay	Pond Inlet	Clyde River	Qikiqtarjuaq	Pangnirtung Iqaluit	Total
100	199	194	55	83	80	711
200	199	194	55	83	80	811
300	199	194	55	83	80	911
400	199	194	55	83	80	1011
500	199	194	55	83	80	1111

Remainder of stock TALCs

SI	AI	ES	EB
408	1	1	0
308	1	1	0
208	1	1	0
108	1	1	0
8	1	1	0

SI	AI	ES	EB
409	1	0	0
309	1	0	0
209	1	0	0
109	1	0	0
9	1	0	0

SI	AI	ES	EB
410	0	0	0
310	0	0	0
210	0	0	0
110	0	0	0
10	0	0	0

SI	AI	ES	EB
411	0	0	0
311	0	0	0
211	0	0	0
111	0	0	0
11	0	0	0

Two separate sensitivity analysis models were run to test the risks associated with the assumption of proportionality in the non-summer catches. (Details of the analysis are provided in Richard 2011.) The analysis tested the probability of exceeding the TALCs for one or more of the four stocks if the optimal catches were reduced from 90% to 50% of their original (100%) values, assuming various scenarios of summer catch proportions. In the first version of the model, stock proportions were set as normalized lognormals. In the second version, the Somerset Island proportion in the (non-summer) Western Stock Mixture was set as a normalized gamma(1,0.2) distribution, which decreased the contribution to the mixture from the Somerset Island stock from a median of 57.3% for the first version to around 25.5% for the second. In general, the results from both versions of the sensitivity models suggest that assuming the stock proportion assumption is correct results in medium to high risk of exceeding TALCs for Admiralty Inlet, Eclipse Sound and East Baffin Island if the whole optimized catches are taken. Taking a larger proportion in the non-summer seasons is riskier than in summer, especially for the smaller stocks (Eclipse Sound and Admiralty Inlet) in the Western non-summer mixture in the gamma model runs, where the Somerset Island stock contributes fewer animals (Figure 3).

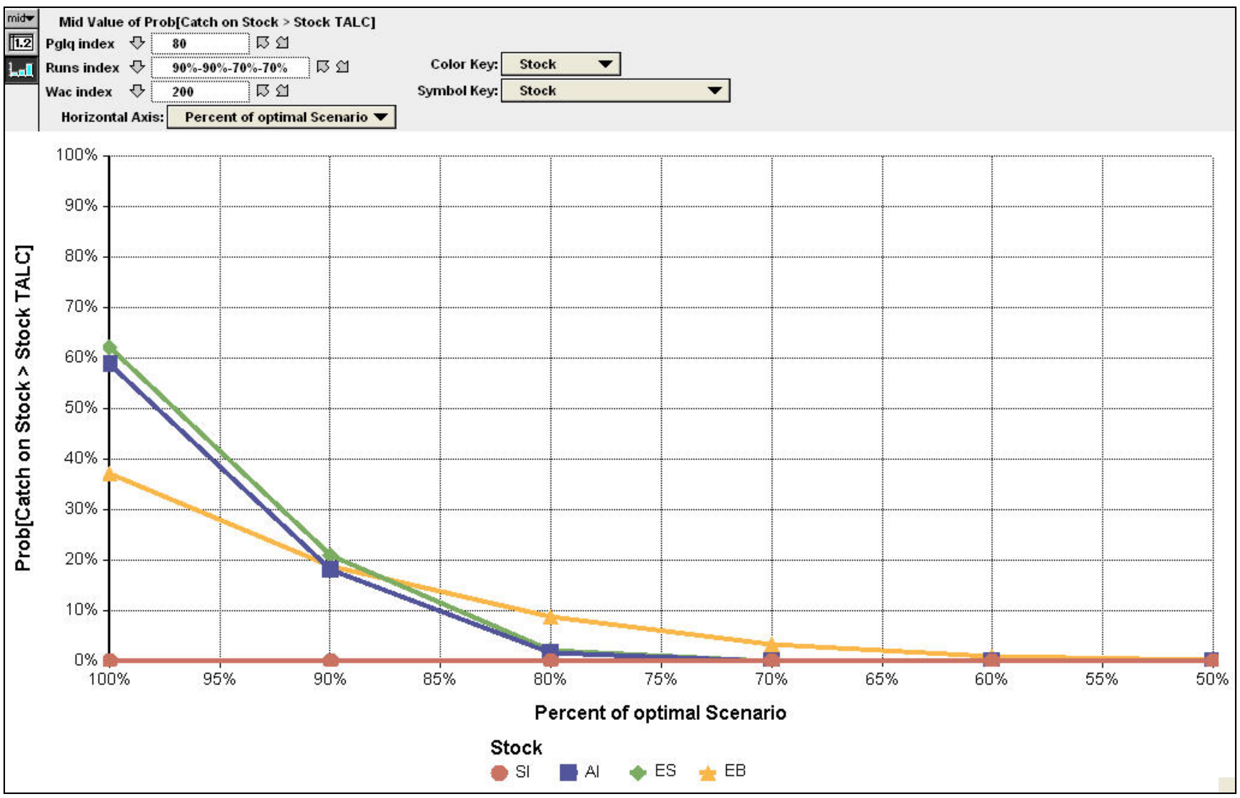

Figure 3. Probability of exceeding stock TALCs if the optimal catches are reduced from 90% to 50% of their original (100%) values, assuming the scenario of summer catch proportions for Arctic Bay, Pond Inlet, Clyde River and Qikiqtarjuaq of 0.9-0.9-0.7-0.7. Except for the SI stock, stock proportions 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.

Co-managers can choose to reduce the allocation models optimized catches to reduce that risk. For all lognormal model summer proportion scenarios, a choice of 90% of the optimized community catches reduced the risk of exceeding TALCs to less than 20% for all stocks. In the gamma model, allocating 80% of the optimal catch brings that probability below 20% for all scenarios but the two lowest summer proportions. Or co-managers can use the two risk models to look at the consequence of the stock proportion assumption under any scenario they might choose to study.

Sources of Uncertainty

The spatial model is based on assumptions derived from published (e.g., see Appendix 1) and anecdotal observations about narwhal distribution and movements. As new data are obtained, the spatial model will likely need to be modified. For example, two narwhals were tagged near Uummannaq, Greenland, in autumn 2007 and 2008. The female tagged in November 2008 transmitted long enough to be tracked through Lancaster Sound to Somerset Island the following spring (Mads Peter Heide-Jorgensen, Greenland Nature Institute, pers. comm.). These tracking data indicate that the entire TALC of the Somerset Island stock should not be allocated in Canada until the proportion of this stock that is taken during the Greenland winter hunt out of Uummannaq is better understood. The Somerset Island stock covers a large area so caution should be used in managing this stock as there also may be some sub-stock structuring. The East Baffin Island stock may also represent more than one summering aggregation. Data used to determine narwhal fidelity to summering stocks is limited to a small number of tagged narwhals that were tracked long enough to show that they returned to their capture area. However, year-to-year variability in use of summering areas by narwhals during their lifetime (circa 100 years) is possible and not resolved by current data. Furthermore, it is possible that climate-induced changes to the sea icescape currently occurring may be responsible for recent (e.g., Somerset Island stock) and future changes to the seasonal distribution of narwhals.

Research needs to focus on methods to estimate the stock proportions in non-summer mixtures from the catch and reduce this major source of uncertainty. Finally, population estimates used in the model are dated, particularly for the Somerset Island stock. New surveys are needed to update population estimates and the corresponding TALCs, as well as the stock proportions used in the model, at least until those proportions are estimated from catch data.

CONCLUSIONS AND ADVICE

A community landed catch allocation tool for Baffin Bay narwhals in Canadian waters was developed using an allocation model and risk analysis. It was structured around a spatial and temporal model of narwhal mixtures based on available information on narwhal seasonal distribution. The model is meant to be an easy-to-use tool for decision-making, to let co-managers explore the impact of allocation decisions on each of the communities harvesting the Baffin Bay stocks. The allocation tool does not apply to the Northern Hudson Bay population or narwhals in the Parry Islands, Jones Sound or Smith Sound.

A structured optimization version and a simpler, iterative version of the allocation model are available. The allocation tool allows co-managers to explore the impact of allocation decisions by varying the amounts of landed catches by communities at both ends of the range of the four stocks and setting the proportions of the catch that are to be taken in the summer season. Once the decisions parameters are set, the allocation tool produces possible solutions that maximize community catches, particularly for those with large historic narwhal catches, while minimizing the risk of over-exploitation of any one stock. As the proportion of animals belonging to any particular stock in the non-summer community harvest is unknown, the model assumes 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.

Four sets of scenarios were run to illustrate the types of results that can be produced by the allocation tool. In general, the results indicated that optimal landed catch levels for Arctic Bay and Pond Inlet, and for Clyde River and Qikiqtarjuaq combined, can be more than 138. Under certain scenarios for some communities the optimized catches could be in excess of 300. These results are based on the assumption that narwhals from different stocks are available to hunters in proportion to stock size during the spring and fall migrations. Two separate sensitivity analysis models, using normalized lognormal and gamma(1,0.2) distributions, were run to test this assumption. The results generally indicated that assuming the stock proportion assumption is correct results in a medium to high risk of exceeding TALCs for Admiralty Inlet, Eclipse Sound and East Baffin Island if the entire optimized catches are taken. Results varied depending on variables input to the model but, in general, reducing the community allocations to 80-90% of the optimized catches significantly reduced the risk of exceeding a stock's TALC. The two risk models can be used by co-managers to assess the consequence of the stock proportion assumption under any scenario.

SOURCES OF INFORMATION

This Science Advisory Report is from the May 6, 2011 meeting of the National Marine Mammal Peer Review Committee (NMMPRC): advice on community allocations for harvesting Baffin Bay Narwhals. Additional publications from this process will be posted as they become available on the Fisheries and Oceans Canada Science Advisory Schedule at www.dfo-mpo.gc.ca/csas-sccs/index-eng.htm.

Dietz, R., Heide-Jørgensen, M.P., Richard, P., Orr, J., Laidre, K.L., and Schmidt, H.C. 2008. Movements of narwhals (*Monodon monoceros*) from Admiralty Inlet monitored by satellite telemetry. Polar Biol. 31: 1295-1306.

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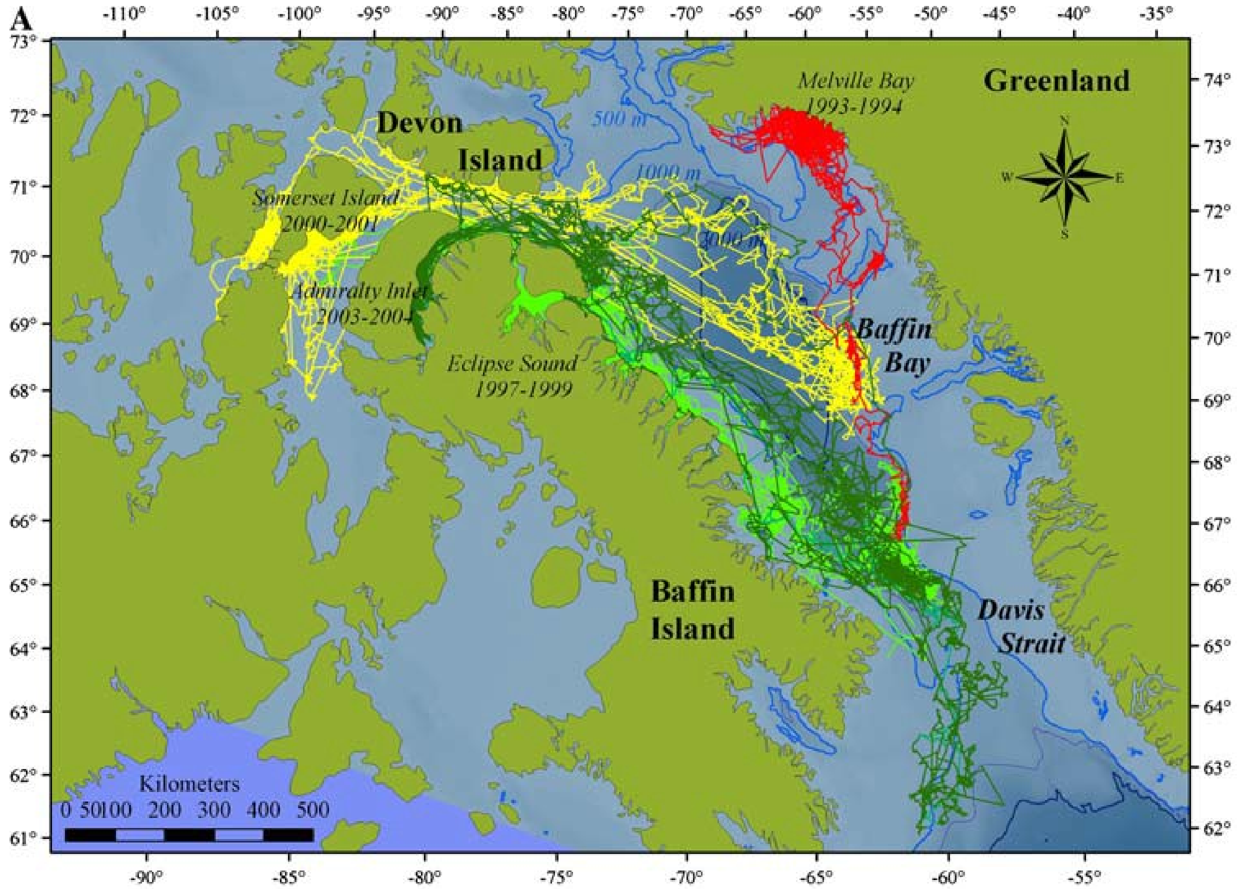
Richard, P.R. 2011. Allocation model for landed catches from Baffin Bay narwhal stocks. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/056. iv + 27 p.

APPENDIX 1



Tagged narwhal tracklines illustrating general movement patterns considered in developing the community allocation model. Tracklines represent narwhals tagged in Admiralty Inlet (dark green), Somerset Island (yellow), Eclipse Sound (light green) and Melville Bay, Greenland (red). (from Dietz et al. 2008).

FOR MORE INFORMATION

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