Report of the Third Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales

Report of the Third Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales[1]

The Workshop was held at the Southwest Fisheries Science Center (SWFSC), La Jolla, California from 18-20 April 2016. The list of participants is given as Annex A.

1. INTRODUCTORY ITEMS

1.1 Convenors' opening remarks

Donovan and Punt (co-Convenors) welcomed the participants to the Workshop. They thanked Weller and the SWFSC for yet again hosting this meeting, the third in a series of workshops examining the rangewide status of North Pacific gray whales (and see IWC, 2015b; 2016). The output from this process is intended to assist in the updating of the IUCN/IWC western gray whale Conservation Management Plan[2] and the general provision of conservation and management advice for North Pacific gray whales.

1.2 Election of Chair

Donovan was elected Chair.

1.3 Appointment of rapporteurs

Weller, Lang and Punt were appointed rapporteurs with assistance from the Chair and others as appropriate.

1.4 Adoption of Agenda

The adopted agenda is given as Annex B.

1.5 Documents and data available

The list of documents is given as Annex C. Annex G provides an updated schematic of present knowledge of North Pacific gray whale distribution and migration.

2. PROGRESS ON 'NON-MODELLING' RECOMMENDATIONS AND NEW DATA

2.1 Update on comparison of identified gray whales in Mexico, off central California and in the PCFG with a focus on mothers and calves

Weller presented an update of information on photo-identification and related research that has been conducted since the two previous Workshops (IWC, 2015b; 2016). The comparison of gray whales identified off Mexico to those identified off Sakhalin and Kamchatka is unchanged from the earlier paper (Urbán R. *et al.*, 2013). A new research undertaking involves comparing gray whale photo-identification images collected opportunistically mostly by commercial whale watching boats off the US west coast to existing catalogues from Sakhalin Island and the PCFG (Weller, pers. comm.).

Table 1 provides an update of the information on available photo-identification data for the North Pacific from that developed at the first Workshop (IWC, 2015b).

Continued efforts to collect shore-based photo-identification images of mother-calf pairs passing by central California concurrent to the annual NOAA calf count continued in 2015, resulting in a catalogue that now spans the period 2012-15 (Weller, pers. comm.) Finally, in 2015 and 2016 a remotely operated hexacopter was used during the NOAA calf count to obtain aerial images of mother-calf pairs to examine length, girth and body condition (Perryman, pers. comm.).

2.2 Comparison of photographs (and genetic material) of gray whales from areas of the Okhotsk Sea and elsewhere in Asia with the Sakhalin and Kamchatka catalogues

Annex D provides a summary of gray whale photo-identification and genetic matching within the western North Pacific. Based on the reported results, two sets of mixing proportions were generated and used in the age structured model described in table 3 of SC/A16/GW02. Table 3a of that paper lists data for the eastern Sea of Japan/Pacific coast of Japan that are based on 'definite' matches/non-matches and table 3b includes the 'likely' matches/nonmatches.

2.3 Development of Single Nucleotide Polymorphisms (SNP) assays for use with gray whales

Table 2 summarises the available samples available for genetic analyses – this is an update to the table presented in the first rangewide Workshop (IWC, 2015b).

Bickham noted that whole genome sequencing of two whales sampled off Sakhalin Island and one whale sampled off Barrow, Alaska, had been completed. These sequences were used to identify 96 SNP loci linked to genes with known functions. Using primers designed from the sequence surrounding these SNPs, 36 biopsies representing 29 gray whales sampled off Sakhalin between 2011 and 2013 were successfully genotyped at 88 of these gene-associated markers, 2 molecular sexing markers and 2 mitochondrial markers. A report detailing these results will be provided for review at SC/66b, and both the genome and primer sequences will be made publicly available through the National Center for Biotechnology Information, allowing researchers in other labs to use this SNP panel in future gray whale studies. Genotyping of samples collected from Sakhalin whales in 2014 and 2015 is planned, and Bickham and his team are trying to identify additional samples from the eastern North Pacific to facilitate a comparative analysis in the future. Such an analysis has the potential to identify differences between Sakhalin whales that overwinter in the eastern North Pacific and any that remain in the western North Pacific year-round.

The Workshop thanked Bickham for this information and looked forward to the full paper that would be presented at SC/66b. In discussion, it was noted that environmental changes have probably resulted in several cycles of splitting and merging between eastern and western North Pacific gray whales over the past 100,000 years, which could affect the magnitude of any such differences, and thus the likelihood that they would be detected.

Lang reported that additional efforts to identify SNP loci in gray whales were underway at SWFSC. Genotyping by-sequencing (GBS) is being conducted on samples (n=190) collected from PCFG whales, whales feeding off Sakhalin Island, and whales feeding north of the Aleutians. GBS utilises a highly multiplexed approach that includes the use of restriction enzymes to reduce genome complexity and is

[1]Presented to the Scientific Committee meeting as SC/66b/Rep07.
[2]*https://www.iucn.org/wgwap/rangewide_initiative/; https://iwc.int/current-future-conservation-management-plans.*

Table 1

Photo-identification data for North Pacific gray whales.

Location	Photos	Catalogue size	Years	Season(s)
Mexico lagoons	Yes	7,000+ IDs	2006-present*;	Primarily Jan.-Apr.
Mexico offshore	Yes	No catalogue; <100 IDs	2007-13	Primarily Jan.-Apr.
California (31-41°N)	Yes	No catalogue; opportunistic/whalewatchers	-	South/northbound migration
Central California	Yes	<150 IDs; shore-based mother/calves	2012-present	North migration Apr.-May
PCFG (41°-52°N)	Yes	>1,500 IDs	Primarily 1980s-2000s*	Primarily Jun.-Nov. opportunistic year round
Aleutians (52°N)	?	N/A	N/A	N/A
Kodiak	Yes	<250 IDs	2002-12 some annual gaps; 2015	Primarily Aug.-Sep.
US Bering Sea	Yes	<10 IDs; opportunistic (St Lawrence Island)	2012	Aug.
Chukchi-Beaufort Sea	Yes	<40 IDs	2013	Aug.-Sep.
Chukotka	No	A catalogue is being developed	N/A	N/A
East Kamchatka	Yes	<160 IDs	2004-12	Primarily Jul.-Aug.
Okhotsk Sea, west of Kamchatka	Yes	No catalogue; opportunistic	1990s-2000s	N/A
Sakhalin	Yes	<250 IDs	1994-present (no data in 1996)	Primarily Jul.-Oct.
Korea	No	N/A	N/A	N/A
Japan: Pacific	Yes	No catalogue; <10 IDs	1990s-2000s	N/A
Japan: Sea of Japan	Yes	No catalogue; 1 ID	2014	Mar.-Apr.
China	Yes	No catalogue; 1 ID	2011	Nov.

*Some data to 1970s.

predicted to result in hundreds to thousands of genotyped SNP markers. These samples have been submitted for sequencing and the resulting data are expected to be available in the next month. Although SNPs identified using this approach are intended to be a random subset from the genome, it was noted that comparison of these sequence data with the genome data generated in Bickham's study could provide information on whether these SNPs are associated with identified genes.

The Workshop thanked Lang for this information. There was some discussion of what might be learned by comparing samples collected during the early field efforts off Sakhalin Island, when photo-identification studies indicated that the feeding ground was used by 100 or fewer whales, to samples collected more recently when the abundance was higher (*ca* 170). It was noted that at least for the Russia-US research programme, efforts were made to avoid sampling individuals more than once, such that samples collected in later years of the study, when many of the individuals had already been biopsied, were not necessarily representative of the whales using the Sakhalin feeding ground during those years. However, it was noted that it would be worthwhile to explore other approaches (e.g. using close kin approaches to estimating abundance) to augment mark-recapture estimates of abundance as well as the use of effective population size estimators, to explore whether changes in abundance over time based on photo-identification data were also reflected in the genetic data.

2.4 Updated information from the eastern North Pacific

Weller provided an update on a recent survey, the Collaborative Large Whale Survey (CLaWS), conducted jointly by the SWFSC and the Alaska Fisheries Science Center. This survey, which took place between 9 July and 9 November 2015, was devoted to the assessment of several large whale species off the US and Canadian west coast between northern California and Kodiak, Alaska. A major component of this effort was the completion of the first range-wide assessment of gray whale feeding grounds south of the Aleutians. Photo-identification images of ~140 individuals were obtained, and 92 biopsies were collected. The majority of photo-identifications and biopsies were obtained off the coast of British Columbia, with a smaller proportion collected off Kodiak, Alaska. Although the coastal waters between the US-Canadian border and Kodiak, Alaska were covered twice during the survey, no gray whales were sighted within this area.

Processing of the gray whale photo-identification data collected on CLaWS is near completion, and the resulting catalogue will be sent to Cascadia for comparison with their catalogue of whales sighted within the PCFG range. In discussion, it was noted that B. Gisborne, who typically surveys the southern and western portion of Vancouver Island, reduced his survey effort during the 2015 season; as such, the data from CLaWS from that area will be particularly valuable in filling in this gap in survey effort.

A recent analysis shows that a high number of calves (36 of 56) born to known PCFG mothers seen prior to 2013 have been documented returning to the PCFG area (Perez *et al*., 2015).

Counts of southbound migrating whales off California form the basis of abundance estimation for the eastern North Pacific stock of gray whales. Previous assessments span the period 1967-2011. The summed estimate of migration abundance in 2011 was 20,990 (95% HPDI=19,230-22,900). Two new field counts, for the 2014/15 and 2015/16 migrations respectively, have been completed and will serve as the basis for updated estimates of abundance to be presented at the 2017 Scientific Committee meeting (Weller, pers. comm.).

The Workshop thanked Weller for this important new information and looked forward to receiving the full report of the CLaWS cruise in due course. It emphasised the value of conducting photographic comparisons with all catalogues in the North Pacific in addition to the catalogue of animals from the PCFG range.

2.5 Updated abundance and trend estimates for the PCFG by identifying and using additional photographic sources

Laake reported that an updated abundance estimate for the PCFG, incorporating data from 2013 and 2014, is in preparation. This will add to the previously reported time-series of estimates between 1996 and 2012.

The Workshop welcomed this news, but agreed that for the purposes of the present work, the previous estimates would be used (and see Item 4).

Table 2

Summary of available samples of gray whales (not all have been analysed and there may be some overlap between studies included here). When known, the number of individuals (*I*) sampled is included in parentheses after the total number of whales sampled.

Region	Reference	*N (I)*	Years	Months
Mexico				
Baja California, Bahía Ballenas	Goerlitz *et al.* (2003)	2	1996	Mar.
Baja California, Bahía Magdalena	Alter *et al.* (2009)	34 (32)	2001-02, 2005-06	Feb.-Mar.
Baja California, Bahía Magdalena	Martinez, pers. comm.	119	2012-14	-
Baja California, offshore, San Jose del Cabo	Goerlitz *et al.* (2003)	1	1996	Mar.
Baja California, Ojo de Liebre lagoon	Alter *et al.* (2009)	24	2001-02, 2005-06	Feb.-Mar.
Baja California, Ojo de Liebre lagoon	Goerlitz *et al.* (2003)	14	1997	Feb.-Mar.
Baja California, Ojo de Liebre lagoon	Martinez, pers. comm.	85	2012-14	-
Baja California, San Ignacio lagoon	Alter *et al.* (2009)	57 (56)	2001-02, 2005-06	Feb.-Mar.
Baja California, San Ignacio lagoon	Goerlitz *et al.* (2003)	66	1996, 1997	Feb.-Mar.
Baja California, San Ignacio lagoon	Martinez, pers. comm.	97	2012-14	-
Baja California, San Ignacio lagoon	D'Intino *et al.* (2013)	51 (40)	1996-97	-
Eastern North Pacific (not specified)	Alter *et al.* (2007)	42	-	-
Migration				
CA/OR/WA (89), AK (9), Chukotka (5)	LeDuc *et al.* (2002)	104	1979-2000	All
PCFG/South				
Pacific Northwest, (not identified as PCFG)	Lang *et al.* (2014)	27 (21)	1996-2012	July-Nov.
Pacific Northwest	Alter *et al.* (2012)	16	150-2690 ybp	?
Pacific Northwest (not yet compared with photo data)	Lang, pers. comm.	158	2011-15	All except Mar.
PCFG Pacific Northwest	Ramakrishnan *et al.* (2001)	45	-	?
Pacific Northwest	Lang *et al.* (2014)	113 (71)	1996-2010	Apr.-Dec.
Pacific Northwest	D'Intino *et al.* (2013)	86 (59)	1996-2010	Jul.-Nov.
Pacific Northwest	Frasier *et al.* (2011)	40	1995-2006	Jul.-Nov.
Pacific Northwest	Steeves *et al.* (2001)	16	1995-96	Jun.-Nov.
Southeast Alaska				
Alaska, Kodiak	Lang, pers. comm.	18	2001, 2005, 2015	Jul.-Sep.
Northeast Chukchi Sea				
Alaska, Barrow	Lang *et al.* (2014)	17 (14)	1997-98, 2000, 2002, 2010	Jul.-Sep.
Alaska, Barrow	Quakenbush, pers. comm.	5	2011	Aug.
Northern Bering Strait/Southern Chukchi Sea				
Russia, Chukotka	Kanda *et al.* (2010)	7	2008	Jun.-Oct.
Russia, Chukotka	Meschersky *et al.* (2015)	112 (86)	2001, 2003-05, 2007-08, 2010	-
Russia, Chukotka	Ilyashenko, pers. comm.	~150	-	-
Russia, Chukotka	Lang *et al.* (2014)	75 (71)	1994, 2001, 2003-05	Aug.-Nov.
Russia, Koryak	Meschersky *et al.* (2015)	21 (17)	2010	Jun.-Aug.
Russia, Koryak	Lang *et al.* (2014)	21 (17)	2010	Jun.
Sakhalin				
Russia, Sakhalin Island	Meschersky *et al.* (2015)	22 (21)	2010-11	-
Russia, Sakhalin Island	Lang, reported	198(156)	1995-2007, 2010-11	Jul.-Sep.
Russia, Sakhalin Island	LeDuc *et al.* (2002)	45	1995-99	Jun.-Oct.
Russia, Sakhalin Island	Bickham *et al.* (2015)	35 (28)	2011-13	Aug.-Sep.
Russia, Sakhalin Island	Bickham, pers comm.	39	2014-15	Aug.-Sep.
East Kamchatka				
Russia, SE Kamchatka	Meschersky *et al.* (2015)	24 (19)	2004, 2010-11	-
Russia, SE Kamchatka	Lang, pers. comm.	25 (17)	1999, 2004, 2010-11	Jun.-Aug.
Pacific side of Japan				
Japan, Pacific coast	Kanda *et al.* (2010)	5	1995-2007	Jan., Apr.-May, Jul.-Aug.
Sea of Japan				
Japan, Sea of Japan coast	Kanda *et al.* (2010)	1	1996	May
Asia				
China	Lang, pers. comm.	2*	1996, 2011	Nov.-Dec.

2.6 Updated estimates for past and future ship strikes and bycatches throughout the North Pacific

In discussion of the bycatch time-series (hereafter used to include ship strikes, entrapments and entanglements) for the western North Pacific (WNP), it was agreed that only records from 1990 through 2014 would be included given that effort to detect stranded whales was lower prior to that time period. Upon review of the available records, it was agreed to include the four whales entangled off Japan between 2005 and 2007 (Kato *et al.*, 2013) in the time series, as well as the whale bycaught in the Taiwan Strait off China in 2011 (Wang *et al.*, 2015). Details of the WNP bycatch time series are included in Table 3.

Fisheries interactions off Sakhalin Island were also discussed. The histories of fisheries, primarily for salmon, in proximity to the Sakhalin feeding ground are unclear. In recent years, however, there has been a notable increase in set nets in the inshore feeding area and pot gear in the offshore fishing area. No direct observations of bycatch have been recorded off Sakhalin since research efforts began in 1997 but the following cases were noted:

(1) a photo-documented entanglement of a whale in 2012 that was subsequently sighted in 2013 free of the entangling line (Weller *et al.*, 2014);

(2) a dead stranded whale near Chayvo in 2009 (WGWAP-7 2009);

Table 3

Records of gray whales in the WNP that are included in the WNP bycatch time-series.

Date (mm/dd/yy)	Location	Length (m)	Sex	Comment	Reference
5/11/2005	Tomiyama (Tokyo Bay), Chiba, Pacific coast of Japan (35°04'N-139°49'E)	7.81	F	Juvenile	Kato *et al.* (2014)
7/15/2005	Enoshima, Onagawa, Miyagi, Pacific coast of Japan (38°23'N-141°37'E)	12.79	F	-	Kato *et al.* (2014)
7/15/2005	Enoshima, Onagawa, Miyagi, Pacific coast of Japan (38°23'N-141°37'E)	7.75	F	Calf of the adult female from same date	Kato *et al.* (2014)
1/18/2007	Sanriku, Ofunato, Iwate, Pacific coast of Japan (39°09'N-141°54'E)	9.19	F	-	Kato *et al.* (2014)
11/5/2011	Fujian Province, Taiwan Strait, China	13.1	F	-	Wang *et al.* (2015)

(3) a weathered whale carcass found by a hunter on 10 October 2010 on the southeastern coast of Sakhalin (WGWAP-14 2014); and
(4) a verbal report from fisherman working off northeastern Sakhalin of a bycaught whale suspected, but not confirmed, to be a gray whale (WGWAP-14 2014).

With respect to case (3), the hunter who photographed the carcass estimated that it was 8m long. Line associated with the carcass, as shown in photographs, led experts to conclude that entanglement could not be ruled out as the cause of death (37 entanglement experts were contacted via the IWC's entanglement experts' network). Features of the carcass shown in photographs were used by Brownell (pers. comm.) to identify the animal as a gray whale.

The Workshop concluded that although these several cases suggest that fisheries interactions are occurring off Sakhalin, the paucity of available information makes further assessments of this issue difficult. It is clear, however, that in recent years the presence of salmon and pot gear has increased on and near the feeding areas off Sakhalin and therefore is of elevated concern.

The Workshop understood that there was a possibility of a more detailed study of fisheries off Sakhalin being undertaken in the context of the IUCN Western Gray Whale Advisory Panel (WGWAP). The Workshop **encourages** such a study.

3. PROGRESS REPORT ON MODELLING-RELATED ISSUES

The Workshop used the terminology and associated assumptions as agreed during the 2nd Workshop on the Rangewide Review of the Population Structure and Status of North Pacific Gray Whales (IWC, 2016).

(1) *Breeding stocks*. There are up to two extant breeding stocks (Western and Eastern).
(2) *Feeding aggregations*. The eastern breeding stock consists of up to three feeding aggregations depending on hypotheses: Western Feeding Group (WFG), Pacific Coast Feeding Group (PCFG) and 'North'. There is dispersal between the PCFG and North feeding aggregations, but the WFG is demographically independent of the other two feeding aggregations (i.e. there is no permanent movement of animals from the North or PCFG to the WFG).
(3) *Sub-areas*. The model includes 11 geographic sub-areas to explain the movements of gray whales in the North Pacific:
  (a) Vietnam-South China Sea [VSC];
  (b) Korea and western side of the Sea of Japan [KWJ];
  (c) eastern side of the Sea of Japan and the Pacific coast of Japan [EJPJ];
  (d) off northeastern Sakhalin Island [SI];
  (e) areas of the Okhotsk Sea not otherwise specified [OS];
  (f) East Kamchatka and the Kuril Islands [EKK];
  (g) the Northern Bering and Chukchi Sea [BSCS];
  (h) Southeast Alaska [SEA];
  (i) British Columbia to Northern California [BCNC];
  (j) California [CA]; and
  (k) Mexico [M].

The model also includes two 'latent' sub-areas used to link model predictions to observed indices of abundance. These are denoted Calif-3 and BC-BCA-3.

The Workshop focussed on the three priority stock structure hypotheses selected by the Scientific Committee at the 2014 Annual Meeting (IWC, 2015a). These can be summarised (and see Fig. 1) as follows.

(1) *Hypothesis 3a*. Although two breeding stocks (Western and Eastern) may once have existed, the Western stock is assumed to have been extirpated. Whales show matrilineal fidelity to feeding grounds, and the Eastern stock includes three feeding sub-stocks or feeding aggregations: PCFG, Northern Bering Sea (NBS)/ Southern Chukchi (SCH)-Northern Chukchi-Gulf of Alaska ('Northern') and WFG.
(2) *Hypothesis 3e*. Identical to hypothesis 3a except that the Western breeding stock is extant and feeds off both coasts of Japan and Korea and in the northern Okhotsk Sea west of the Kamchatka Peninsula. All of the whales feeding off Sakhalin overwinter in the eastern North Pacific
(3) *Hypothesis 5a*. Identical to hypothesis 3a except that the whales feeding off Sakhalin include both whales that are part of the Western stock and remain in the western North Pacific year-round, and whales that are part of the Eastern stock and migrate to the eastern North Pacific.

3.1 Updated bounds on the proportion of Sakhalin whales that migrate to the eastern North Pacific

Comparisons of photo-identification catalogues collected in Mexico and off Sakhalin, supplemented by results of whales tagged in Sakhalin, have previously been used to estimate confidence bounds on the proportion of adult Sakhalin whales that do not migrate to breeding grounds in Mexico (Cooke, 2015). The earlier results showed that inferences could be sensitive to assumptions about the extent to which immature animals join the migration. This was because the matching rate between animals observed in the WNP and the ENP was significantly lower for immature gray whales than for adult gray whales.

SC/A16/GW06 used data on the reproductive status of migrating gray whales collected off California by Rice and Wolman (1971) to refine the bounds on the proportion of

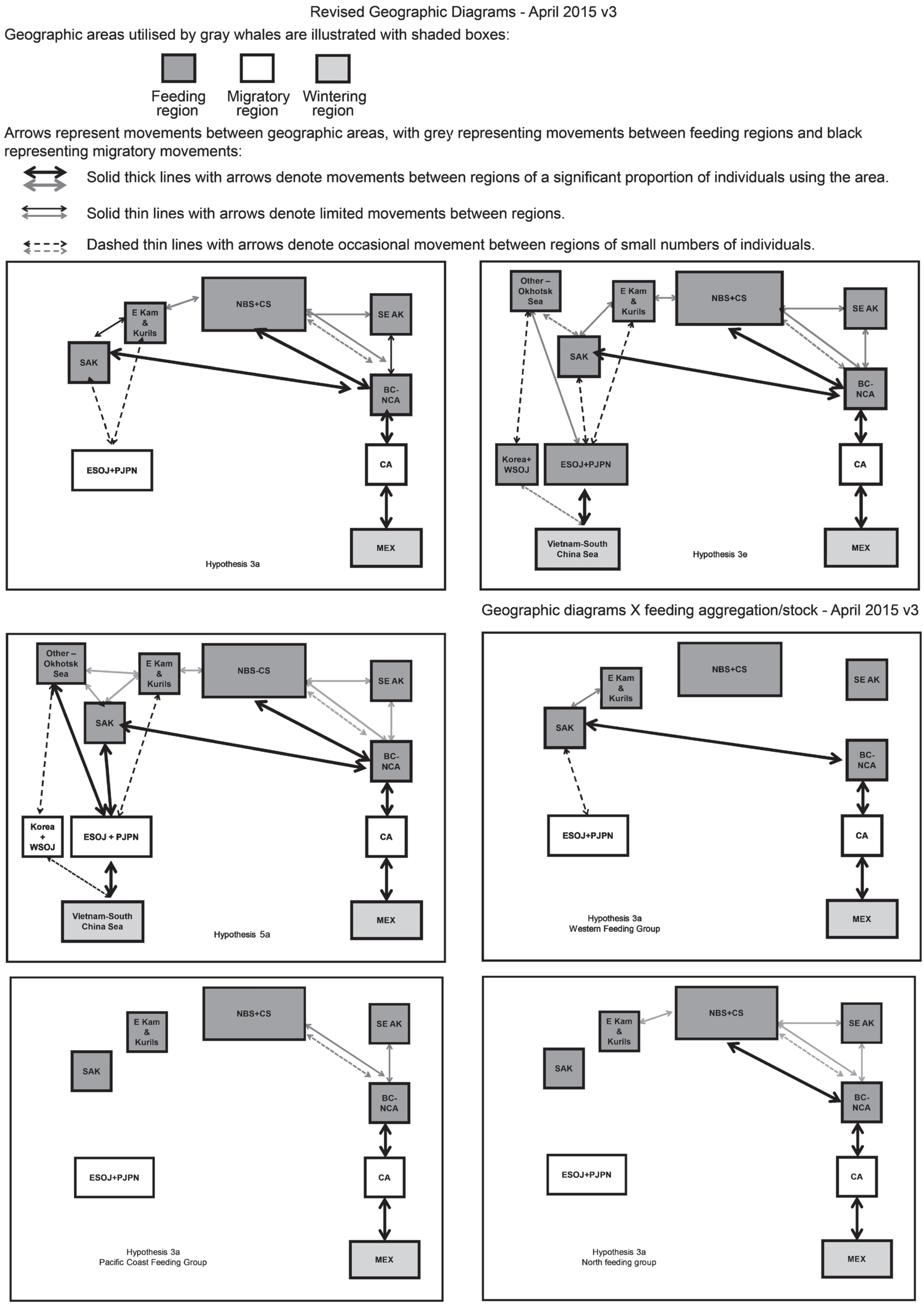
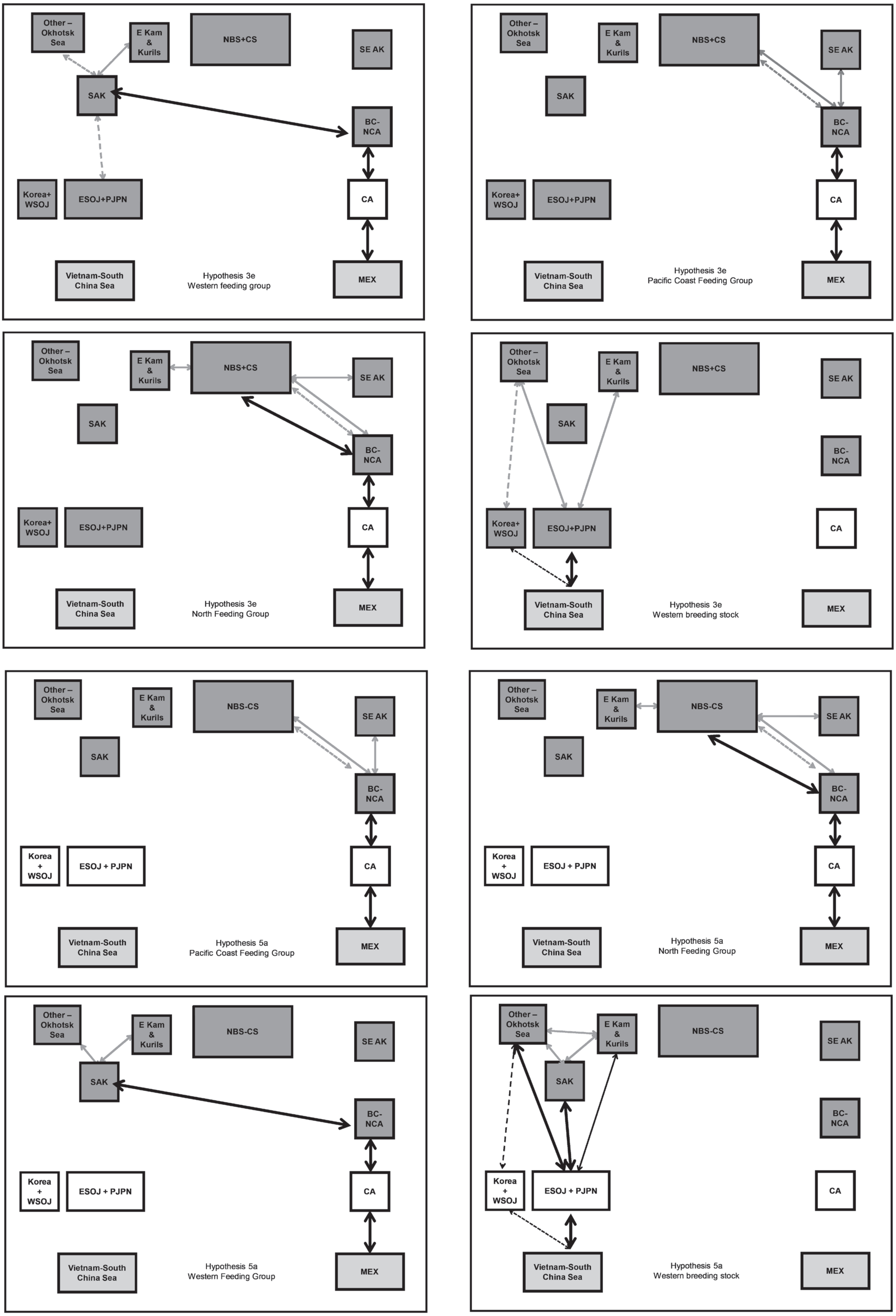


Fig.1. Stock structure hypotheses.


Other – Okhotsk Sea
E Kam & Kurils
NBS+CS
SE AK
SAK
BC-NCA
Korea+ WSOJ
ESOJ+PJPN
CA
Vietnam-South China Sea
Hypothesis 3e
Western feeding group
MEX
Other – Okhotsk Sea
E Kam & Kurils
NBS+CS
SE AK
SAK
BC-NCA
Korea+ WSOJ
ESOJ+PJPN
CA
Vietnam-South China Sea
Hypothesis 3e
Pacific Coast Feeding Group
MEX
Other – Okhotsk Sea
E Kam & Kurils
NBS+CS
SE AK
SAK
BC-NCA
Korea+ WSOJ
ESOJ+PJPN
CA
Vietnam-South China Sea
Hypothesis 3e
North Feeding Group
MEX
Other – Okhotsk Sea
E Kam & Kurils
NBS+CS
SE AK
SAK
BC-NCA
Korea+ WSOJ
ESOJ+PJPN
CA
Vietnam-South China Sea
Hypothesis 3e
Western breeding stock
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Other – Okhotsk Sea
E Kam & Kurils
NBS-CS
SE AK
SAK
BC-NCA
Korea + WSOJ
ESOJ + PJPN
CA
Vietnam-South China Sea
Hypothesis 5a
Pacific Coast Feeding Group
MEX
Other – Okhotsk Sea
E Kam & Kurils
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Korea + WSOJ
ESOJ + PJPN
CA
Vietnam-South China Sea
Hypothesis 5a
Western Feeding Group
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Other – Okhotsk Sea
E Kam & Kurils
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SAK
BC-NCA
Korea + WSOJ
ESOJ + PJPN
CA
Vietnam-South China Sea
Hypothesis 5a
Western breeding stock
MEX

Sakhalin whales that undertake the migration. The revised bounds are not appreciably narrower: between 30% and 100% of mature (aged 7+) Sakhalin whales are estimated to migrate to the ENP. The proportion of immature whales undertaking the migration may be somewhat less. The existence of a breeding ground outside the ENP is thus neither confirmed nor excluded by this new analysis.

The Workshop thanked Cooke for his work in updating the analysis as requested by the previous Workshop. It looks forward to further updates to the estimated bounds when analyses of data on additional confirmed matches and non-matches become available. The Workshop **agreed** that further consideration should be given at SC/66b to whether the analyses should continue to be limited to only those animals included in the Mexican catalogue.

3.2 Development of an age- and sex-structured model

SC/A16/GW02 outlined a sex- and age-structured population dynamics model that can represent the stock hypotheses developed during the previous Workshops (IWC, 2015b; 2016). The model allows for multiple breeding stocks, each of which may consist of several feeding aggregations, multiple feeding and wintering grounds, as well as migratory corridors. Animals can move permanently between feeding aggregations in a pulse or diffusively. The values for the parameters of the model can be estimated by fitting it to data on trends in relative and absolute abundance, in addition to mixing proportions based on mark-resight data, bycatch rates, and estimates of numbers immigrating into the PCFG.

4. UPDATE ON MODELLING FRAMEWORK AND INITIAL RUNS

4.1 Progress on modelling

The modelling framework (SC/A16/GW02) was modified from that presented to the 2015 meeting of the Scientific Committee in that allowance was made for the dispersal rate between the 'north' and 'PCFG' feeding aggregations to be density dependent. Assuming that the dispersal rate is constant over time leads to poor fits to the abundance estimates for the PCFG feeding aggregation (models 12A, 12B and 12C in SC/A16/GW02) and this change was made to address this. In addition, uncertainty was quantified using a bootstrap procedure. SC/A16/GW02 provided example applications of the model based on the three priority stock structure hypotheses (see above). It also provided results for model variants that could be considered further to capture uncertainty regarding the assumptions of the model. SC/A16/GW02 also provided examples of projections in which the subsistence catches for the BSCS subarea (the Chukotka hunt) and the BCNC sub-area (the Makah hunt) are based respectively on the *Gray Whale* and *PCFG SLA*s (*Strike Limit Algorithms*) and where fishing effort (and hence bycatch rate by area) were constant into the future.

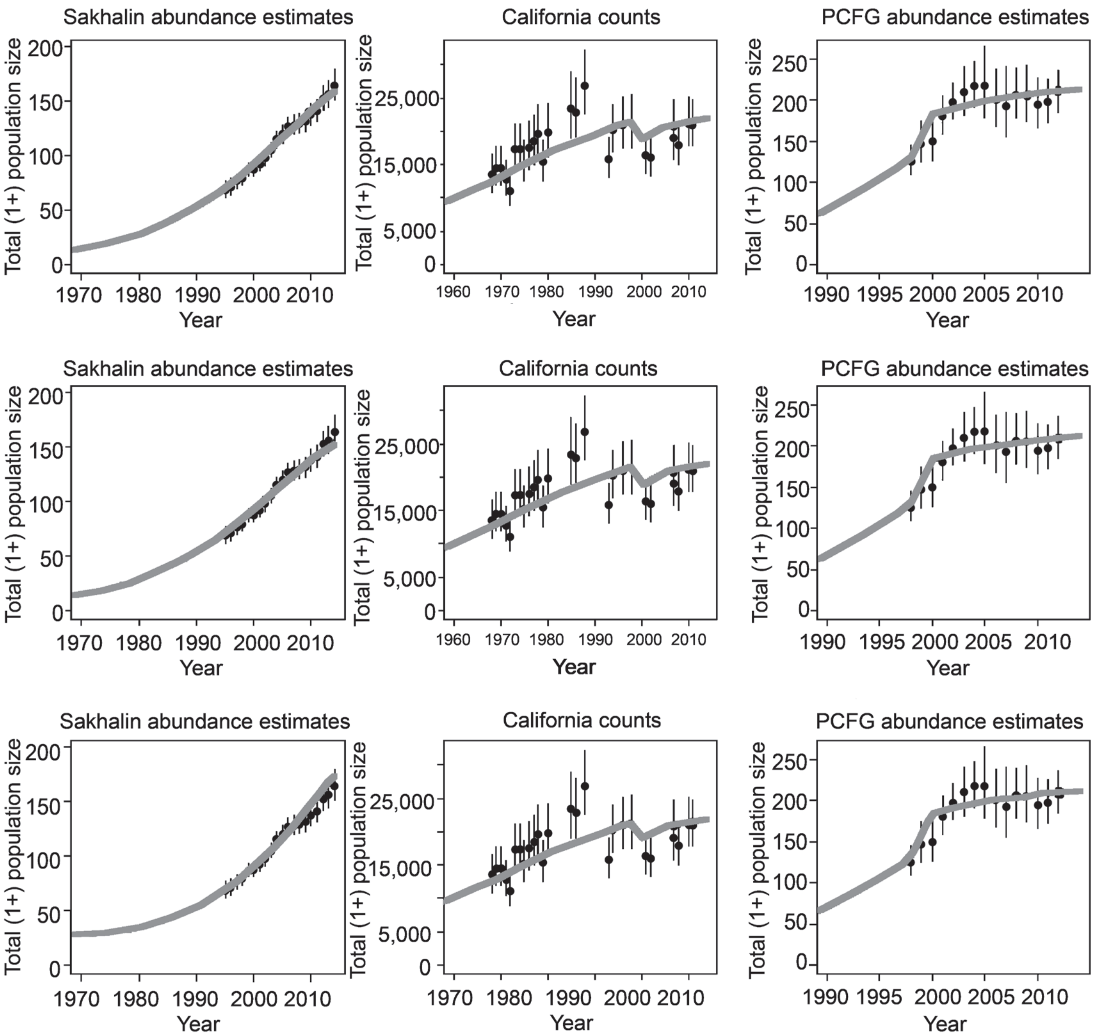

Fig. 2. (a) The plot for the areas with abundance data showing the abundance estimates and their 90% confidence intervals, the fit of the model to the actual data ('deterministic'; solid black lines), and the median and 90% intervals from the 100 replicates (solid grey line and shaded area respectively). The results in this figure pertain to the reference case model. Results are shown for stock hypotheses 3a, 3b and 5a on the upper, middle and lower panels respectively.

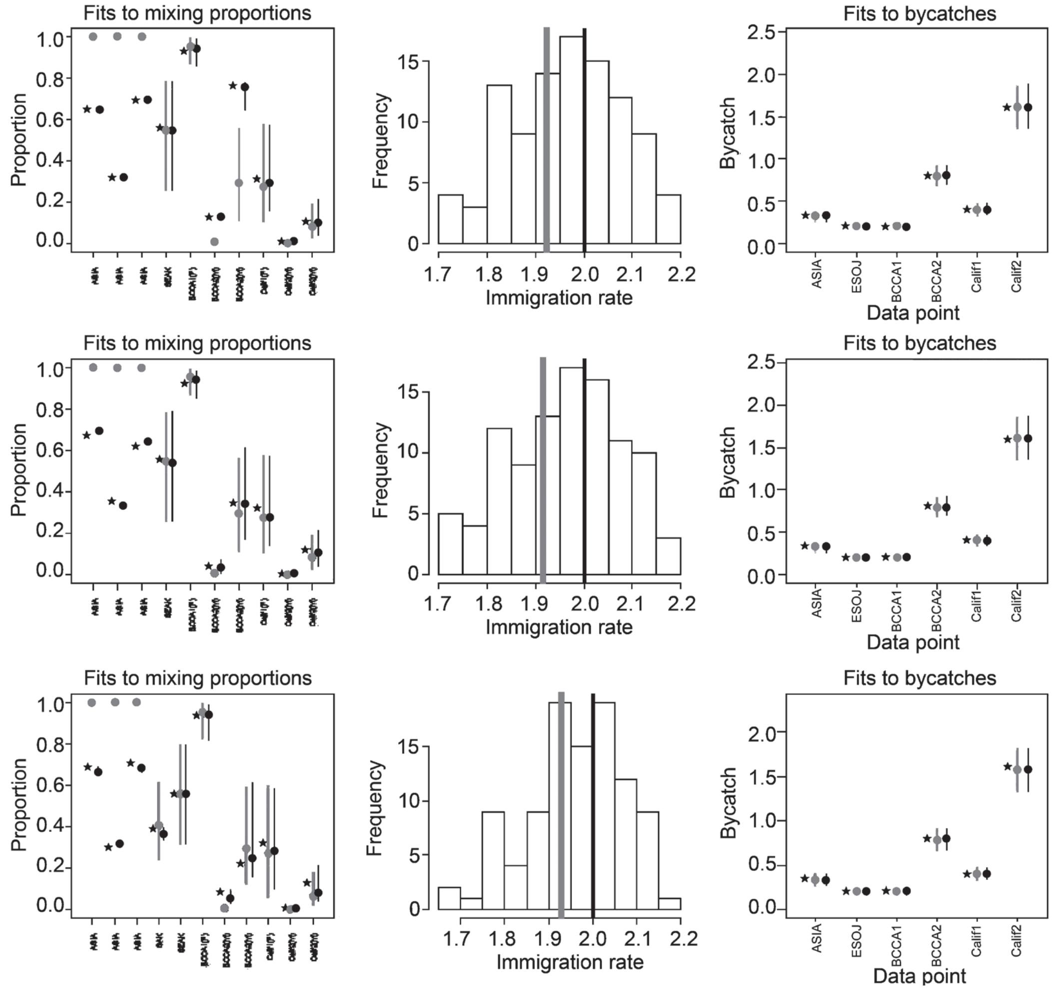

Fig. 2. (b) Summary of the fits to the data on mixing proportions (left column), immigration rate (centre column), and bycatch rates (right panel) for the reference case model. The grey dot and intervals show the median and 90% intervals for the bootstrap data sets, the stars are the fit of the model to the actual data ('deterministic'), and the black dots and lines are median and 90% intervals from the 100 replicates. The histogram in the centre plot show the bootstrap distribution for the immigration rates in the model (the black line is the median of the target values and the grey line the result of the fit to the actual data). The results in this figure pertain to the reference case model. Results are shown for stock hypotheses 3a, 3b and 5a on the upper, middle and lower panels respectively.

SC/A16/GW02 provided three diagnostics plots to assist with the evaluation of the conditioning of the models (see Fig. 2a-c for examples).

(1) The abundance estimates and their 90% confidence intervals, with the fit of the model to the actual data ('deterministic'; solid black lines), and the median and 90% intervals from the 100 replicates (solid grey line and shaded area respectively).
(2) Fits to the data on mixing proportions, immigration rate, and bycatch rates. The grey dot and intervals show the median and 90% intervals for the bootstrap data sets, the stars are the fits of the model to the actual data ('deterministic'), and the black dots and lines are median and 90% intervals from the 100 replicates. The histogram in the centre plot shows the bootstrap distribution for the immigration rates in the model (the black line is the median of the target values and the grey line the result of the fit to the actual data).
(3) Time-trajectories of numbers of mature females by breeding stock/feeding aggregation. The black line is the fit of the model to the actual data ('deterministic'; solid black lines), and the solid grey line and shaded area respectively are the median and 90% intervals from the 100 replicates.

The Workshop noted that the model was generally able to mimic the time-series of abundance estimates and the bycatch rates well. One exception was that the model failed to capture the decline in abundance from 1998 to 2000, even though the model includes a parameter to account for additional mortality. It also failed to mimic well the change in abundance estimates from 1987/88 to 1992/93. The Workshop noted several hypotheses for the latter result, including that migratory behaviour may have changed between 1987/88 and 1992/93 (e.g. differing proportions migrating past the central California census depending upon body condition), but agreed not to change the model without independent data to corroborate this (e.g. data on body condition are available for the years 1997-2003 and 2012 and there are ongoing (since 2015) efforts to collect such data).

The 'deterministic' fit to the immigration rate was close to the pre-specified value. The model predictions of mixing rates for the EJPJ sub-area suggested that 2/3 of the animals in this area were from the Western Feeding Ground (WFG), which is expected given that two of the three identified animals were WFG animals. In general, the model mimics the mixing proportions but some of the fits were poor.

The Workshop requested additional diagnostic plots be developed to show the model predictions of immigration over time as well as the time-trajectories of bycatch. Examples of these figures are shown in Fig. 3.

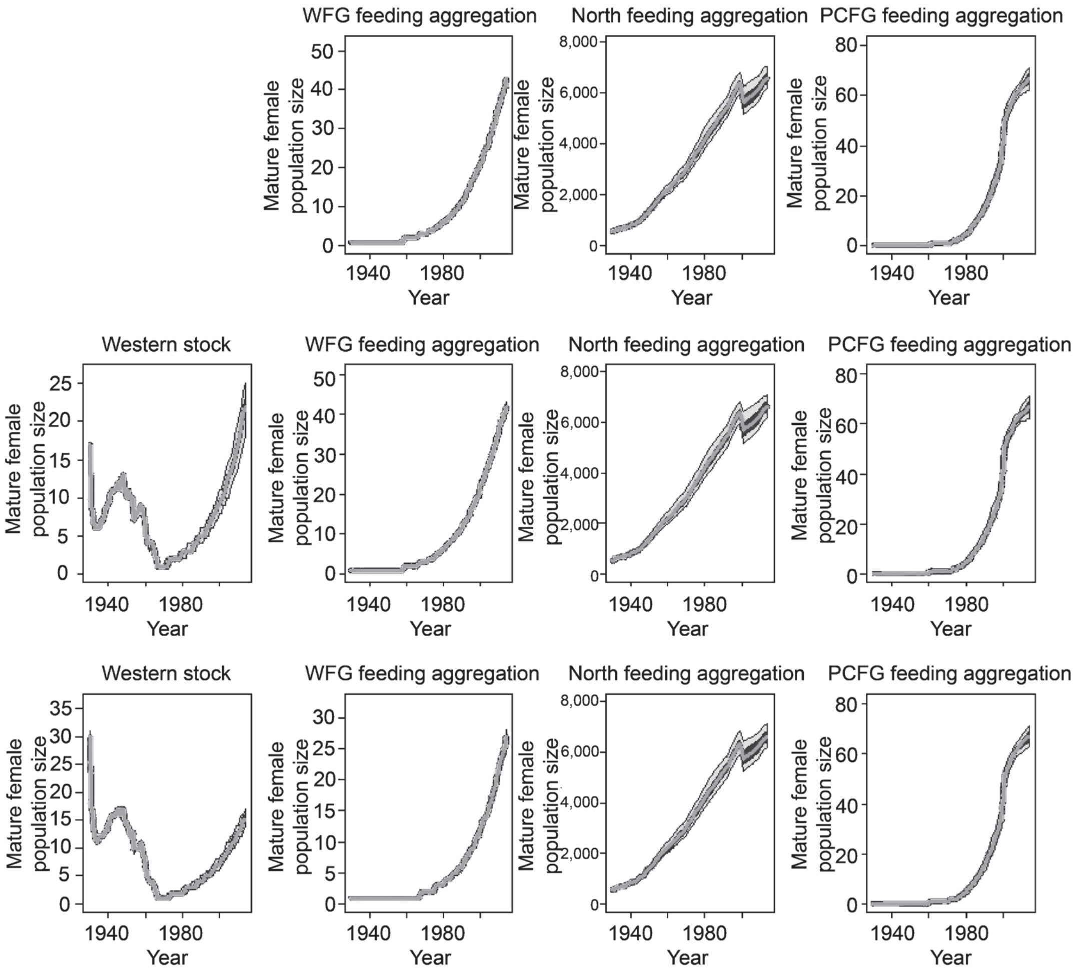

Fig. 2. (c) Time-trajectories of numbers of mature females by stock/feeding aggregation and stock hypothesis (3a, 3b and 5a on the upper, middle and lower panels respectively) for the reference case model. The black line is the fit of the model to the actual data ('deterministic'; solid black lines), and the solid grey line and shaded area respectively are the median and 90% intervals from the 100 replicates.

In conclusion, the Workshop thanked Punt for his thorough work and agreed that these plots provided an appropriate basis for evaluating model performance. It **agreed** that the plot showing the fit to the mixing proportions should be modified to include all the mixing proportions (so the sum of the observed mixing proportions adds to 1 across stocks for each sub-area). The Workshop **encouraged** SWFSC to examine the body condition data mentioned above in relation to the annual ice condition data.

4.2 Finalise data sets by stock structure hypothesis

4.2.1 Removals and abundance estimates

The Workshop agreed to make two changes the time-series of historical removals:

(1) the catches for 2014 in the BSCS sub-area should be 43 males and 81 females (C. Allison, pers. comm.); and
(2) the catch series for EJPJ sub-area should include the catch of 1 (unknown sex) as discussed in Brownell and Kasuya (1999).

Most of the analyses in SC/A16/GW02 were based on annual estimates of the number of dead animals due to bycatch and ship strikes (sensitivity to this was explored to five times this number). As in previous Workshops, the Workshop **reiterated** that the number of dead animals would underestimate, probably considerably, the actual number of animals killed due to bycatch and ship strikes. The Workshop therefore **agreed** to four scenarios regarding based on:

(a) the numbers reported as dead;
(b) the numbers reported as dead or 'seriously injured' *sensu* Carretta *et al.* (base-case); and
(c) four times the numbers reported as dead;
(d) ten times the numbers reported as dead.

The value of four was based on Carretta *et al.* (2016) estimate of the fraction of carcasses recovered of coastal common bottlenose dolphins (0.25, 95% CI=0.20 -0.33), while the value of ten was based on the results of Punt and Wade (2012), who estimated that between 3% and 14% of gray whales that died during the 1999-2000 mortality event were reported.

The bycatches used in the modelling were extended to include bycatch for the BCSC sub-area and were separated between the feeding (June-November) and migratory (December-May) periods for the SEA sub-area (Table 1). Annex D documents the basis for the estimates of bycatch for the VSC and EJPJ sub-areas while Annex E documents the basis for the bycatch/ship strike estimates for the eastern sub-areas. The estimates of bycatch for the VSC and EJPJ sub-areas are assumed to pertain to years 1990-2014, as the reporting of strandings, ship strikes and bycatches off Japan is likely to have been more consistent since 1990.

4.2.2 Abundance estimates

The analyses in SC/A16/GW02 were based on updated abundance estimates and their associated variance covariance matrix for the Sakhalin sub-area based on the

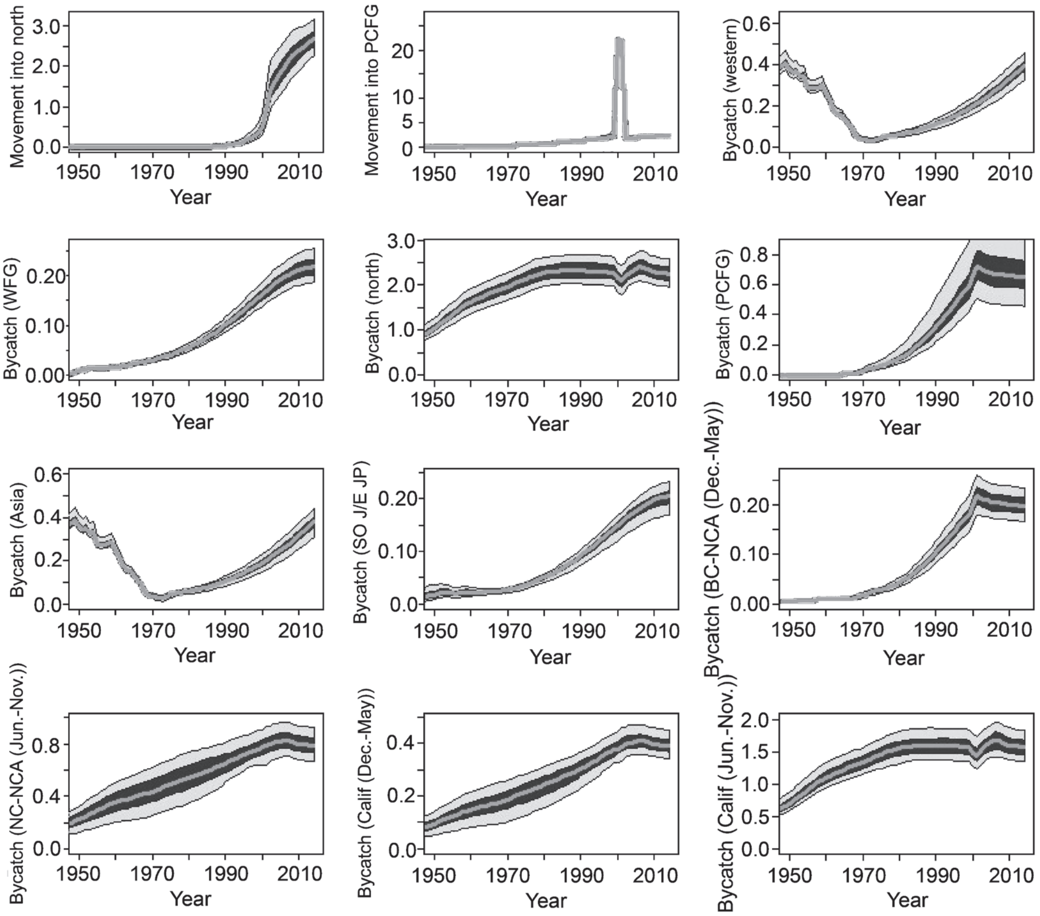

Fig. 3. Time-trajectories of: (a) number dispersing between the 'north' and PCFG' feeding aggregations; (b) bycatch by stock/feeding aggregation; and (c) bycatch by sub-area. The black line is the fit of the model to the actual data ('deterministic'; solid black lines), and the solid grey line and shaded area respectively are the median and 90% intervals from the 100 replicates. The results here pertain to stock structure hypothesis 3e.

Table 4

Scenarios regarding bycatch.

Sub-area	Years	Numbers dead	Dead and serious injury	Numbers dead x 4	Numbers dead x 8
VSC	1990-2014	1/25	??	4/25	8/25
EJPJ	1990-2014	4/25	??	16/25	32/25
SI	1997-2014	1.5/18	??	6/18	12/18
BSCS					
SEA (Jun.-Nov.)					
SEA (Dec.-May)					
BCNC (Jun.-Nov.)					
BCNC (Dec.-May)					
CA (Jun.-Nov.)					
CA (Dec.-May)					

Bayesian version of the model developed by Cooke (e.g. see the report of WGWAP-16). The Workshop **endorsed** use of these abundance estimates as provided in Annex F. Other abundance estimates agreed in IWC (2016) are also provided in Annex F.

4.2.3 Mixing proportions

SC/A16/GW05 provided an update for the availability of PCFG whales by region and season using the database of whale sightings maintained by the Cascadia Research Collective for sightings through 2014. Availability was calculated as the number of observations of whales meeting the IWC definition for PCFG whales (IWC, 2015b) divided by the total number of gray whale observations. Observations were defined as a uniquely identified whale photographically identified by day. Small changes in availability were calculated for PCFG whales in the summer feeding season and migratory season in the northern California to British Columbia region and central and southern California in the feeding season as compared to the values reported in Scordino *et al.* (2014).

The Workshop reviewed the data on the stock identity of animals caught off Japan and **agreed** with the two scenarios (base-case: definite matches/non-matches; sensitivity: definite and likely matches non-matches; table 2a in SC/A16/GW02).

The Workshop thanked Scordino for the updated analyses in SC/A16/GW02, and **agreed** to modify the mixing rates to the values suggested in SC/A16/GW05. Given that the collection of photographs in the CA sub-area during the migration season (December-May) is not random but targeted towards PCFG whales, the Workshop **agreed**

Table 5
Data on mixing proportions (definite and likely matches/non-matches only) to be used when conditioning the models.

Sub-area	Year	Stock concerned	Estimate (assumed SD)
EJPJ	2007[d]	WFG	1 (0.1)
EJPJ	2012[d]	Western	1 (0.1)
EJPJ	2015[d]	WFG	1 (0.1)
EJPJ	2005[l]	Western	1 (0.1)
EJPJ	2007[l]	Western	1 (0.1)
SI	2012	Western	0.40[a] (0.1)
SEA (Jun.-Nov.)	2012	PCFG	0.559 (0.15)
BCNC (Jun.-Nov.)	2012	PCFG	0.951 (0.05)
BCNC (Dec.-May)	2012	WFG	0.002 (0.05)
BCNC (Dec.-May)	2012	PCFG	0.339 (0.15)
CA (Jun.-Nov.)	2012	PCFG	0.472 (0.15)

[a]Stock structure hypothesis 5a only (changed in sensitivity analysis).
[d]Definite; [l]Likely.

Table 6
Factors considered in the model scenarios. The bolded values are the base-levels.

Factor	Levels
Model fitting related	
Stock hypothesis	**3a, 3e, 5a**
Proportion of 'Western' stock in Sakhalin sub-area	**0** (stock hypotheses 3a, 3e), **0.33** (stock hypothesis 5a), 0.70
$MSYR_{1+}$ (western)	As for WFG
$MSYR_{1+}$ (north)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (WFG)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (PCFG)	2%, **4.5%¸** Estimated (common); estimate (separately)
Matches	Definite; Definite+Likely (Table 2)
Immigration into the PCFG	**0, 2**, 4
Bycatches and ship strikes	Numbers dead, M/SI, numbers dead x 4; x numbers dead x 10
Pulse migrations into the PCFG	10, **20**, 30
Bycatch off Sakhalin	**1.5**, 3
Projection-related	
Northern need in final year (from 150 in 2014)	**340**, 530
Struck and lost rate	25% **50%**, 75%
Future effort	**Constant**, Increase by 100% over 100 years
Probability of mismatching a north whale, p_1	**0.01**
Probability of mismatching a PCFG, p_2	0.05 (trials)
PCFG harvest month	**Migratory**

to modify the catch mixing matrix for this combination of sub-area and season so that it is assumed that all animals are equally vulnerable to capture. It also **agreed** that all animals should be assumed to be equally vulnerable to capture, or proportionately to abundance for all areas noted in Table 5 (and see Annex E).

The final mixing proportions are given in Table 5.

4.3 Further development of trials to reflect uncertainty and anthropogenic removals

4.3.1 Base-case models and sensitivity tests

The Workshop **agreed** to the following changes to specifications the base-case model:

(a) the SEA sub-area should be divided into feeding and movement seasons given different bycatch rates in this sub-area seasonally (Table 5); and
(b) the proportion of animals in Sakhalin that are Western stock animals should be set to 0.33 (table 3 of SC/A16/GW06).

The Workshop reviewed the set of factors on which trials could be based suggested in SC/A16/GW06 and made the following changes (see Table 6):

(a) the alternative value for the proportion of Western stock animals in the SI sub-area was changed to 0.33 based on table 3 of SC/A16/GW06;
(b) scenarios in which $MSYR_{1+}$ is estimated should be considered for two cases, one in which $MSYR_{1+}$ is assumed to be the same for all feeding aggregations and the other in which $MSYR_{1+}$ differs among feeding aggregations;
(c) the higher alternative number of 'north' animals immigrating into the PCFG feeding aggregation was reduced from 8 to 4 based upon information provided by Laake, and the fact that the value of 8 provided a poor fit[3] - the case of 8 was retained for the trial involving estimated MSYR to examine whether this might improve the fit;
(d) the scenarios regarding bycatches and ship strikes was updated (see Item 4.2.2);
(e) the assumption that dispersal is not density-dependent was dropped as this assumption leads to poor fits to the available data (SC/A16/GW02); and
(f) two scenarios regarding the bycatch off Sakhalin were added (see Annex F).

Table 7 lists the trials. The bulk of the trials involve one change from the base-case models. Trials 16-20 involve two changes to the base-case trials. Trial 16 involves two changes that should make achieving conservation objectives

[3]The immigration rate of 0 is consistent with observations that internal recruitment into the PCFG has been high in recent years (Perez *et al*., 2015).

Table 7
The trial specifications.

Trial	Description/stock hypothesis	PCFG in BSCS	$MSYR_{1+}$ North	$MSYR_{1+}$ PCFG	$MSYR_{1+}$ WFG	% Western in Sakhalin	PCFG immigration	PCFG pulse	Bycatch multiplier
1A	Reference 3a	No	4.5%	4.5%	4.5%	0	2	20	1
1B	Reference 3e	No	4.5%	4.5%	4.5%	0	2	20	1
1C	Reference 5a	No	4.5%	4.5%	4.5%	0.33	2	20	1
2A	Lower MSYR PCFG 3a	No	**4.5%**	**2%**	**4.5%**	0	2	20	1
2B	Lower MSYR PCFG 3e	No	**4.5%**	**2%**	**4.5%**	0	2	20	1
2C	Lower MSYR PCFG 5a	No	**4.5%**	**2%**	**4.5%**	0.33	2	20	1
3A	Higher MSYR WFG and North 3a	No	**5.5%**	**5.5%**	**4.5%**	0	2	20	1
3B	Higher MSYR WFG and North 3e	No	**5.5%**	**5.5%**	**4.5%**	0	2	20	1
3C	Higher MSYR WFG and North 5a	No	**5.5%**	**5.5%**	**4.5%**	0.4	2	20	1
4C	Higher Western breeding stock in Sakhalin 5a	No	4.5%	4.5%	4.5%	**0.7**	2	20	1
5A	Alternative matches 3a	No	4.5%	4.5%	4.5%	0	2	20	1
5B	Alternative matches 3e	No	4.5%	4.5%	4.5%	0	2	20	1
5C	Alternative matches 5a	No	4.5%	4.5%	4.5%	0.33	2	20	1
6A	Lower PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**0**	20	1
6B	Lower PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**0**	20	1
6C	Lower PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**0**	20	1
7A	Higher PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**4**	20	1
7B	Higher PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**4**	20	1
7C	Higher PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**4**	20	1
8A	Lower Pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2	**10**	1
8B	Lower Pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2	**10**	1
8C	Lower Pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2	**10**	1
9A	Higher pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2	**30**	1
9B	Higher pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2	**30**	1
9C	Higher pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2	**30**	1
10A	Bycatch x 4 3a	No	4.5%	4.5%	4.5%	0	2	20	**4**
10B	Bycatch x 4 3e	No	4.5%	4.5%	4.5%	0	2	20	**4**
10C	Bycatch x 4 5a	No	4.5%	4.5%	4.5%	0.33	2	20	**4**
11A	Bycatch x 10 3a	No	4.5%	4.5%	4.5%	0	2	20	**10**
11B	Bycatch x 10 3e	No	4.5%	4.5%	4.5%	0	2	20	**10**
11C	Bycatch x 10 5a	No	4.5%	4.5%	4.5%	0.33	2	20	**10**
12A	Bycatch = 3 in SI 3a	No	4.5%	4.5%	4.5%	0	2	20	**2 for SI**
12B	Bycatch = 3 in SI 3e	No	4.5%	4.5%	4.5%	0	2	20	**2 for SI**
12C	Bycatch = 3 in SI 5a	No	4.5%	4.5%	4.5%	0.33	2	20	**2 for SI**
13A	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2	20	1
13B	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2	20	1
13C	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0.33	2	20	1
14A	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2	20	1
14B	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2	20	1
14C	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0.33	2	20	1
15A	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Est**	**Est**	**Est**	0	2	20	1
15B	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Est**	**Est**	**Est**	0	2	20	1
15C	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Est**	**Est**	**Est**	0.33	2	20	1
16A	Lower PCFG immigration & higher bycatch 3a	No	4.5%	4.5%	4.5%	0	**0**	20	**4**
16B	Lower PCFG immigration & higher bycatch 3e	No	4.5%	4.5%	4.5%	0	**0**	20	**4**
16C	Lower PCFG immigration & higher bycatch 5a	No	4.5%	4.5%	4.5%	0.33	**0**	20	**4**
17A	MSYR estimated and lower pulse 3a	No	**Est**	**Est**	**Est**	0	2	**10**	1
17B	MSYR estimated and lower pulse 3e	No	**Est**	**Est**	**Est**	0	2	**10**	1
17C	MSYR estimated and lower pulse 5a	No	**Est**	**Est**	**Est**	0.33	2	**10**	1
18A	MSYR estimated and higher pulse 3a	No	**Est**	**Est**	**Est**	0	2	**30**	1
18B	MSYR estimated and higher pulse 3e	No	**Est**	**Est**	**Est**	0	2	**30**	1
18C	MSYR estimated and higher pulse 5a	No	**Est**	**Est**	**Est**	0.33	2	**30**	1
19A	MSYR estimated and higher immigration 3a	No	**Est**	**Est**	**Est**	0	**4**	20	1
19B	MSYR estimated and higher immigration 3e	No	**Est**	**Est**	**Est**	0	**4**	20	1
19C	MSYR estimated and higher immigration 5a	No	**Est**	**Est**	**Est**	0.33	**4**	20	1
20A	MSYR estimated and much higher immigration 3a	No	**Est**	**Est**	**Est**	0	**8**	20	1
20B	MSYR estimated and much higher immigration 3e	No	**Est**	**Est**	**Est**	0	**8**	20	1
20C	MSYR estimated and much higher immigration 5a	No	**Est**	**Est**	**Est**	0.33	**8**	20	1

for the PCFG feeding aggregation more difficult while all but one set of the remaining multi-factor trials combine estimates of feeding-aggregation-specific MSY rates with different assumptions regarding immigration into the PCFG feeding aggregation. Trial 20 explores whether it is possible to mimic the data when the immigration into the PCFG feeding aggregation is 8 and $MSYR_{1+}$ is estimated by feeding aggregation.

The Workshop examined the stock structure hypotheses developed by IWC (2015b; 2016). Most of these hypotheses are either equivalent to stock structure hypotheses 3a, 3e and 5a or there are insufficient data to parameterise them. In review, however, the Workshop decided that hypothesis 6b[4], which was initially assigned low priority because it would be represented in the same way as hypothesis 5a in the modelling framework, should be reconsidered. This hypothesis assumes that the WFG feeding aggregation, *per se*, does not exist, but that

[4]Two breeding stocks – one includes whales from the PCFG and Northern feeding sub-stocks that migrate to Mexico and largely breed with each other, and the other includes all whales that feed off Sakhalin and breed largely with each other whether on the ENP or WNP migratory routes/wintering grounds.

whales feeding in the SI sub-area represent an extant Western breeding stock that utilises two wintering grounds (VSC and M). In discussion, it was noted that modelling this hypothesis does differ from that of hypothesis 5a, in that: (1) all catches off Japan are assumed to be Western stock animals; and (2) the abundance estimates off Sakhalin are assumed to relate only to the Western stock. Thus the Workshop **agreed** that an attempt should be made to implement this stock structure hypothesis and evaluate the conservation implications.

4.3.2 Projections

The aim of the projections is to explore the population consequences of various scenarios regarding anthropogenic removals of gray whales, with a view to informing future conservation and management. Table 6 lists the factors to be considered in the projections. The Workshop **agreed** that the projections would assumed that future subsistence whaling in the BCNC sub-area would occur during the migratory period and would be based on 'the *SLA* variant with research' (IWC, 2015b) recommended by the Scientific Committee.

It was **agreed** that the results of the projections should be summarised by:

(a) time-trajectories of mature female numbers relative to carrying capacity, catches by stock due to aboriginal whaling, and incidental catches by stock;
(b) the conservation-related metrics used for the implementation for the PCFG *SLA*; and
(c) a table for the proportion of catch of WFG whales by sub-area (20 and 100 years).

5. WORK PLAN

The following work plan was **agreed** by the Workshop, recognising that this was ambitious and would depend upon the availability of individuals.

(1) Scordino and Reeves to update and circulate to the Steering Group the bycatch values for the BCNC subarea by 25 April.
(2) Punt to distribute the diagnostic plots for the base-case trials by 30 April.
(3) Punt to fit all of models in Table 4 as well as a base-case model based on the new stock structure hypothesis and distribute the results to the Steering Group by mid-May (Punt, Donovan, Wade, Cooke, Reeves).
(4) Steering Group to provide comments on the model fits and guidance on projection runs to Punt by 20 May.
(5) Punt to conduct the projections in accordance with guidance from the Steering Group and present results to SC/66b.

6. ADOPTION OF REPORT

The report was adopted at 11:44 on 21 April 2016, subject to final editorial corrections. Donovan thanked Weller for his hard work in organising the excellent facilities and assisting with the hotel. He thanked all participants and especially the rapporteurs for their co-operative spirit. Most of all he thanked Punt for his dedicated, innovative and tireless work during both the intersessional period and the meeting itself.

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Annex A

List of Participants

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Annex B

Agenda

1. Introductory items
   1.1 Convenor's opening remarks
   1.2 Election of Chair
   1.3 Appointment of rapporteurs
   1.4 Adoption of Agenda
   1.5 Documents and data available
2. Short report on progress on 'non-modelling' recommendations and new data since SC66a
   2.1 Update on comparison of identified gray whales in Mexico, off central California and in the PCFG with a focus on mothers and calves
   2.2 Comparison of photographs (and genetic material) of gray whales from areas of the Okhotsk Sea and elsewhere in Asia with the Sakhalin and Kamchatka catalogues
   2.3 Development of Single Nucleotide Polymorphisms (SNP) assays for use with gray whales
   2.4 Updated information from the eastern North Pacific
   2.5 Updated abundance and trend estimates for the PCFG by identifying and using additional photographic sources
   2.6 Updated estimates for past and future ship strikes and bycatches throughout the North Pacific
3. Progress report on modelling-related issues
   3.1 Updated bounds on the proportion of Sakhalin whales that migrate to the eastern North Pacific
   3.2 Development of an age- and sex-structured model
4. Update on modelling framework and initial runs
   4.1 Progress on modelling since SC/66a
   4.2 Finalise datasets by stock structure hypothesis
      4.2.1 Removals and abundance estimates
      4.2.2 Abundance estimates
      4.2.3 Mixing proportions
   4.3 Further development of trials to reflect uncertainty and anthropogenic removals
5. Work plan
6. Adoption of Report

Annex C

List of Documents

SC/A16/GW

1. Punt, A.E. Progress report on rangewide gray whale modelling.
2. Punt, A.E. A revised age-structured model for exploring the conceptual models developed for gray whales in the North Pacific.
3. Agenda for Workshop.
4. Weller, D.W., Lang, A.R. and Brownell, R.L., Jr. Gray whale photo/genetic match-no match summary in Western North Pacific: data for April 2016 IWC rangewide Workshop.
5. Scordino, J. and Calambokidis, J. Availability of PCFG whales by region during the migratory and feeding season: update with data through 2014.

Annex D

Gray Whale Photo/Genetic Match-No Match Summary in Western North Pacific

D.W. Weller, A.R. Lang and R.L. Brownell, Jr.

Table 1

Summary of information available regarding matches and non-matches (genetic or photographic) for gray whales from the western North Pacific. Due to the tsunami in 2011, it is assumed that DNA or tissue is no longer available for the genetic records marked with an asterisk. Information from: Kato *et al.*, 2015; Lang *et al.*, 2011; Weller *et al.*, 2002; 2003; 2008; 2012; 2015.

No.	Type	Date	Country	Sample	Comments
1	Genetic*	07/04/1995	Japan	Stranding Female 9.5m	Hokkaido (Pacific). Haplotype identified as G or O in Kanda *et al.* (2010). Haplotype G is found in low frequencies among both sampled Eastern North Pacific (ENP) whales and sampled Sakhalin whales (found in two individuals off Sakhalin). Haplotype O has not been found among biopsied Sakhalin individuals and is found in low frequencies among sampled ENP animals.
2	Genetic*	16/05/1996	Japan	Killed	Hokkaido (Sea of Japan). Haplotype identified as A in Kanda *et al.* (2010). Haplotype A is common in both sampled ENP and sampled Sakhalin whales (and is one of the two most commonly identified haplotypes in whales biopsied off Sakhalin).
3	Photo-ID	22/07/1997	Japan	Sighting	Kochi (Pacific). Photos unusable for matching (Kato and Tokuhiro, 1997).
4	Photo-ID	06/05/2003	Japan	Sighting	Shizuoka (Pacific). Photos unusable for matching. Two animals present.
5	Photo-ID Genetic*	11/05/2005	Japan	Entangled Female 7.81m	Chiba (Pacific). Marginal quality photo – no match to Sakhalin Russia-US catalogue. Haplotype identified as L or U in Kanda *et al.* (2010). Based on mtDNA and microsatellite data produced at SWFSC obtained from whole genome amplification products brought from Japan for analysis, this whale has haplotype U and is not a genetic match (based on microsatellites) for any of the whales the Russia-US team sampled off Sakhalin. Haplotype U has not been found in any biopsied Sakhalin whales but has been found in one individual biopsied off SE Kamchatka. This haplotype is not common among sampled ENP whales. Note that this whale and the whale entangled off Japan on 01 August 2007 (see note in record 8 below) share the same haplotype, although the microsatellite data indicates that they are not a mother-offspring pair. The possibility that these whales share an alternate relationship (e.g. maternal half-sibs) has not yet been assessed.
6	Photo-ID Genetic*	15/07/2005	Japan	Entangled Mother 12.8m	Miyagi (Pacific). Was with a calf. Photos unusable for matching. Haplotype of the adult female identified as Z in Kanda *et al.* (2010)[2]. Haplotype Z is found in only a few whales sampled in the ENP and among one individual sampled off Sakhalin
7	Photo-ID Genetic*	18/01/2007	Japan	Bycatch stranding Female 9.19m	Iwate (Pacific). Useable quality photo, match to Sakhalin Russia-US catalogue. Haplotype identified as Haplotype B in Kanda *et al.* (2010), which is consistent with haplotype data we have for this same whale when sampled off Sakhalin in 2006. Haplotype B is found in moderate frequencies in sampled ENP whales and in high frequencies among biopsied Sakhalin animals.
8	Genetic*	01/08/2007	Japan	Entangled Female 12.33m	Hokkaido (Pacific). Identified as Haplotype L or U in Kanda *et al.* (2010). Based on mtDNA and microsatellite data produced at SWFSC obtained from whole genome amplification products brought from Japan for analysis, this whale has haplotype U and is not a genetic match (based on microsatellites) for any whales sampled off Sakhalin by the Russia-US team. Haplotype U has not been found in any biopsied Sakhalin whales but has been found in one individual biopsied off SE Kamchatka. It is uncommon among sampled ENP whales. See note above in record 5 regarding this whale.

Cont.

No.	Type	Date	Country	Sample	Comments
9	Photo-ID	??/11/2011	China	Bycatch	Taiwan Strait (Pacific). Useable quality photo (left side only) – no match to Sakhalin Russia-US catalogue.
No.	Type	Date	Country	Sample	Comments
	Genetic				Identified as haplotype R in Wang *et al.* (2015) and confirmed by SWFSC. Based on SWFSC microsatellite genotypes, not a genetic match to any whale sampled off Sakhalin by the Russia-US team. This haplotype has not been identified among Sakhalin whales and is relatively uncommon among sampled ENP whales.
10	Photo-ID	12/03/2012	Japan	Sighting	Irako port, Tawara-city. Excellent quality photos – no match to Sakhalin RussiaUS catalogue.
11	Photo-ID	06/04/2014	Japan	Sighting	Teradomari. Excellent quality photos – no match to Sakhalin Russia-US catalogue. Inter-Japan match shows same whale as record 14 (Aoyagi *et al.*, 2016).
12	Photo-ID	03/2015	Japan	Sighting	Kozu Shima. Useable quality photo, match to Sakhalin Russia-US catalogue. Same whale as record 13.
13	Photo-ID	04-05/2015	Japan	Sighting	Suruga Bay. Marginal quality photos, match to Sakhalin Russia-US catalogue. Same whale as record 12.
14	Photo-ID	03/2015	Japan	Sighting	Teradomari. Fair quality photos – no match to Sakhalin Russia-US catalogue. InterJapan match shows same whale as record 11 (Aoyagi *et al.*, 2016).
15	Genetic	7/12/1996	China	Stranding	Yellow Sea. Baleen is archived at SWFSC but thus far, efforts to extract DNA from this baleen sample have failed and no genetic data has been obtained. See details in Zhao (1997).
16	Photo-ID	07/2000	Russia	Sighting	Paramushir Island, Kuril Islands (Okhotsk Sea). Good quality photos, match to Sakhalin Russia-US catalogue. Same whale as record 17.
17	Photo-ID	09/2000	Russia	Sighting	Shantar Island (Okhotsk Sea). Good quality photos, match to Sakhalin Russia-US catalogue. Same whale as record 16.
18	Photo-ID	06/2000	Russia	Sighting	Bering Island (Bering Sea). Good quality photos, match to Sakhalin Russia-US catalogue.
19	Photo-ID	01/2016	Japan	Sighting	Sagami Bay (Pacific). Fair quality photos, match to Sakhalin Russia-US catalogue. Same whale as records 12 and 13.
20	Photo-ID	02/2016	Japan	Sighting	Miyake-Jima (Pacific). Fair quality photos, match to Sakhalin Russia-US catalogue. Same whale as records 12, 13 and 19.
21	Photo-ID	03/2016	Japan	Stranding	Chiba (Pacific). Photos unusable for matching.

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Annex E

Non-whaling Anthropogenic Mortality of Gray Whales: 2016 Update

J. Scordino and R.R. Reeves

Scordino and Mate (2012) summarised bycatch and ship strike mortality from stranding databases, human-whale interaction databases and ship strike databases maintained by NOAA's Northwest Region and Southwest Region (databases did not include events in Alaska). Their summary also included bycatches and ship strikes reported by Baird *et al.* (2002) for 1990-95 in British Columbia and all reported ship strikes and bycatch events from 1978-2010 in the USA. Scordino and Mate (2012) chose to calculate annual human-caused mortality rates based on data from 1990-2010 for the USA and 1990-95 for Canada because fishing effort in the two jurisdictions was more similar in those years than earlier in the time-series and because stranding networks in the USA were well established by 1990, giving more confidence that animals stranded in the USA with signs of human-caused mortality would have been reported.

In 2014, Scordino *et al.* (2014) presented new estimates of annual bycatch and ship strike rates for the time period of 2008-12 using a classification procedure developed by NOAA (2012) to account for the uncertainty in outcome of injuries to large whales due to entanglements and ship strikes. This procedure makes it possible to prorate mortality values for injuries based on the known fates of individual whales observed with similar injuries in the past. Gray whale deaths and injuries were documented through fisheries observer programmes, self-reporting by fishermen and sailing captains, reporting by the public and examinations of dead whales on the beach in the USA and Canada. Every report was documented in a Canadian or US government database. Based on descriptions in the databases, each event was determined to have been either a death, a serious injury, or a non-serious injury, based on NOAA (2012). All US events were assessed for serious vs non-serious injury by a NOAA working group (Carretta *et al.*, 2014) and that group's results were used as the basis for scoring the events reported by Scordino *et al.* (2014) and summarised by Scordino *et al.* (2016).

Here we use data for 2007-14 from NOAA serious injury reports (Carretta *et al.*, 2013; 2014; 2015; 2016) received from James Carretta (NOAA, SWFSC, La Jolla, pers. comm.) for the US and from Paul Cottrell (Department of Fisheries and Oceans, Sydney, BC, pers. comm.) for Canada to update the input data on incidental mortality given in IWC (2016). The previous tables of ship strike and bycatch mortality in IWC (2016) incorrectly classified two observations at Valdez-Cordova as being from Southeast Alaska instead of from the Far North region; these have been rectified in the new tables provided here (Tables 1 and 2).

Table 1

Reported (observed) totals and 8-year averages of deaths and serious injuries of gray whales by region and season, 2007-14.

	Observed 2007-14		Average 2007-14	
Region	Feeding	Migration	Feeding	Migration
FN-Puget Sound	2.5	3.5	0.31	0.44
Kodiak	0	0	0.00	0.00
Southeast Alaska	1	0.75	0.13	0.09
BC-NCA	To be updated			
California	12.5	20.5	1.56	2.56

Table 2

Reported observed totals and 8-year averages of deaths of gray whales by region and season, 2007-14.

	Observed 2007-14		Average 2007-14	
Region	Feeding	Migration	Feeding	Migration
FN-Puget Sound	0	1	0.00	0.13
Kodiak	0	0	0.00	0.00
Southeast Alaska	0	0	0.00	0.00
BC-NCA	To be updated			
California	7	8	0.88	1.00

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Annex F

Specifications of the Population Model

A. BASIC CONCEPTS AND STOCK STRUCTURE

The aim of the projections is to explore the population consequences of various scenarios regarding anthropogenic removals of gray whales, with a view to informing future conservation and management. The model distinguishes 'breeding stocks' and 'feeding aggregations'. Breeding stocks are demographically and genetically independent whereas feeding aggregations may be linked through dispersal of individuals[1], though perhaps at very low rates for some combinations of feeding aggregations. Each breeding stock/feeding aggregation is found in a set of sub-areas, each of which may have catches (commercial, aboriginal or incidental), proportions of breeding stock/feeding aggregation mixing[2] in those sub-areas, observed bycatch rates[3], and indices of relative or absolute abundance. Removals may be specified to sets of months during the year for some sub-areas if the various feeding aggregations are not equally vulnerable to catches throughout the year for those sub-areas. The trials capture uncertainty regarding stock structure and MSYR, as well as uncertainty regarding bycatch and immigration.

The region concerned, the North Pacific, is divided into 11 sub-areas. The model also includes two 'latent' sub-areas used to link model predictions to observed indices of abundance. These are denoted CA-3 and BCNC3. There are up to two extant *breeding stocks* (Western and Eastern). The Eastern breeding stock consists of up to three *feeding aggregations* depending on the stock structure hypothesis: Western Feeding Group (WFG), Pacific Coast Feeding Group (PCFG) and 'North'. There is dispersal between the PCFG and North feeding aggregations, but the WFG is demographically independent of the other two feeding aggregations (i.e. there is no *permanent* movement of animals from the North or PCFG to the WFG or vice-versa).

The trials consider four stock structure hypotheses.

(1) *Hypothesis 3a*. Although two breeding stocks (Western and Eastern) may once have existed, the Western stock is assumed to have been extirpated. Whales show matrilineal fidelity to feeding grounds, and the Eastern stock includes three feeding aggregations: PCFG, Northern Bering Sea (NBS)/Southern Chukchi (SCH)-Northern Chukchi-Gulf of Alaska ('Northern') and WFG.

(2) *Hypothesis 3e*. Identical to hypothesis 3a except that the Western breeding stock is extant and migrates off both coasts of Japan and Korea and in the northern Okhotsk Sea west of the Kamchatka Peninsula. All of the whales feeding off Sakhalin overwinter in the eastern North Pacific.

(3) *Hypothesis 5a*. Identical to hypothesis 3a except that the whales feeding off Sakhalin include both whales that are part of the extant Western stock and remain in the western North Pacific year-round, and whales that are part of the Eastern stock and migrate between Sakhalin and the eastern North Pacific.

(4) *Hypothesis 6b*. This hypothesis assumes that the WFG feeding aggregation does not exist, but that whales feeding in the SI sub-area represent an extant Western breeding stock that utilises two wintering grounds (VSC and M). This hypothesis differs from hypothesis 5a, in that: (1) all removals off China and Japan are assumed to be Western breeding stock animals; and (2) the abundance estimates for Sakhalin are assumed to relate only to the Western breeding stock.

B. BASIC DYNAMICS

The population dynamics are based on the standard age- and sex-structured model, which has formed the basis for the evaluation of *Strike Limit Algorithms* for eastern North Pacific gray whales, i.e.:

$$
\begin{aligned}
&N_{t+1,0}^{m/f,i,j} = 0.5B_{t+1}^{i,j} && a=0 \\
&N_{t+1,a}^{m/f,i,j} = ((N_{t,a-1}^{m/f,i,j} - C_{t,a-1}^{m/f,i,j})\,S_{a-1} + I_{t,a-1}^{m/f,i,j})\tilde{S}_t^{i,j} && 1 \le a \le x\text{-}1 \\
&N_{t+1,x}^{m/f,i,j} = ((N_{t,x}^{m/f,i,j} - C_{t,x}^{m/f,i,j})S_x + (N_{t,x-1}^{m/f,i,j} - C_{t,x-1}^{m/f,i,j})\,S_{x-1} + I_{t,\mathrm{x}}^{m/f,i,j} + I_{t,\mathrm{x}-1}^{m/f,i,j})\,\tilde{S}_t^{i,j} && a=x
\end{aligned}
\qquad \text{(B.1)}
$$

where:

$N_{t,a}^{m/f,i,f}$ is the number of males/females of age a in feeding aggregation j of breeding stock i at the start of year t;

$C_{t,a}^{m/f,i,f}$ is the number of anthropogenic removals of males/females of age a in feeding aggregation j of breeding stock i during year t (whaling is assumed to take place in a pulse at the start of each year);

[1]The term 'dispersal' is used here in the sense of 'effective dispersal', and refers to permanent movement of individuals among feeding aggregations. Such individuals become part of the feeding aggregation to which they move and contribute to future reproduction.
[2]Mixing is defined here as two feeding aggregations that overlap at some time on the feeding grounds, but do not interbreed.
[3]Bycatch is understood to include mortality or 'serious' injury from entanglement or entrapment in fishing gear (or debris) and ship strikes.

S_a is the annual survival rate of animals of age a in the absence of catastrophic mortality events (assumed to be the same for males and females):

$$S_a = \begin{cases} S_0 & \text{if } a = 0 \\ S_{1+} & \text{if } 1 \le a \end{cases} \tag{B.2}$$

S_0 is the calf survival rate;

S_{1+} is the survival rate for animals aged 1 and older;

$\tilde{S}_t^{i,j}$ is the amount of catastrophic mortality (represented in the form of a survival rate) for feeding aggregation j of breeding stock i during year t (catastrophic events are assumed to occur at the end of the year after mortality due to anthropogenic removals and non-catastrophic natural causes, and dispersal; in general $\tilde{S}_t^{i,j}=1$, i.e. there is no catastrophic mortality);

$B_{t+1}^{i,j}$ is the number of births to feeding aggregation j of breeding stock i during year t+1;

$I_{t,a}^{s,m/f}$ is the net dispersal of female/male animals of age a into feeding aggregation j of breeding stock i during year t; and

x is the maximum (lumped) age-class (all animals in this and the x-1 class are assumed to be recruited and to have reached the age of first parturition). x is taken to be 15.

C. DENSITY-DEPENDENCE

Density-dependence is assumed to be a function of numbers of animals aged 1 and older by feeding ground relative to the carrying capacity by feeding ground. The density-dependence component for feeding aggregation j of breeding stock i is the sum of the density-dependence components by feeding aggregation weighted by the proportion of animals from feeding aggregation j of breeding stock i that are found on each feeding ground, i.e.:

$$F(i,j,t) = \sum_A \psi^{A,i,j} \left(X^{A,i,j} (N_t^{1+,A} / K^{1+,A})^z \right) / \sum_A \psi^{A,i,j} X^{A,i,j} \tag{C.1}$$

where

z is the degree of compensation;

$\psi^{A,i,j}$ indicates whether sub-area A impacts density-dependence for feeding aggregation j of breeding stock i;

N_t^{1+A} is the number of 1+ animals on feeding ground A at the start of year t:

$$N_t^{1+,A} = \sum_i \sum_j X^{A,i,j} \sum_{a=1}^{x} (N_{t,a}^{m,i,j} + N_{t,a}^{f,i,j}) \tag{C.2}$$

K_t^{1+A} is the carrying capacity for feeding ground A:

$$K^{1+,A} = \sum_i \sum_j X^{A,i,j} \sum_{a=1}^{x} (N_{-\infty,a}^{m,i,j} + N_{-\infty,a}^{f,i,j}) \tag{C.3}$$

$X^{A,i,j}$ is the proportion of animals in feeding aggregation j of breeding stock i that are found in feeding ground A[4] (see Table 1).

The number of births at the start of year t for feeding aggregation j of breeding stock i, $B_t^{i,j}$, is given by:

$$B_t^{i,j} = b_t^{i,j} N_t^{f,i,j} \tag{C.4}$$

where $N_t^{f,i,j}$ is the number of mature females in feeding aggregation j of breeding stock i at the start of year t:

$$N_t^{f,i,j} = \sum_{a=a_m}^{x} N_{t,a}^{f,i,j} \tag{C.5}$$

a_m is the age-at-maturity (the convention of referring to the mature population is used here, although this actually refers to females that have reached the age of first parturition);

$b_t^{i,j}$ is the probability of birth/calf survival for mature females in feeding aggregation j of breeding stock i during year t:

$$b_t^{i,j} = \max(0, b_K \{1 + A^{i,j}(1 - F(I,j,t))\}) \tag{C.6}$$

b_K is the average number of live births per year per mature female at carrying capacity; and

$A^{i,j}$ is the resilience parameter for feeding aggregation j of breeding stock i.

[4]It is usually the case that $\Sigma X^{A,i,j} = 1$. However, for gray whales, this is not necessarily the case because removals can take place in the various feeding grounds at different times. What is then important is the relative values of the $X^{A,i,j}$ among feeding aggregations for a given feeding ground.

Table 1

The mixing matrices for stock structure hypotheses 3a, 3e, 5a and 6b. The γs denote the estimable parameters of the catch mixing matrix and the χs denote values that are varied in the tests of sensitivity. Note that the 'CA-3' sub-area is included so that the surveys (= encompasses all methods for obtaining abundance estimates) cover all of the PCFG, Sakhalin and north feeding aggregations while the BCNC-3 sub-area is included so that the surveys for the BCNC sub-area pertain only to the PCFG feeding aggregation.

Breeding stock	Sub-area															
Feeding aggregation	VSC	KWJ	EJPJ	OS	SI	EKK	BSCS	SEA (J-N)	SEA(D-M)	BCNC (J-N)	BCNC (D-M)	BCNC-3	CA (J-N)	CA (D-M)	CA-3	M
(a) Hypothesis 3a (no extant Western breeding stock)																
Eastern WFG	-	-	1	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
North	-	-	γ_1	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_5	1	γ_6	1	1	1
(b) Hypothesis 3e (extant Western breeding stock)																
Western	1	1	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Eastern WFG	-	-	γ_7	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
North	-	-	-	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_6	1	γ_6	1	1	1
(c) Hypothesis 5a (with Western breeding stock in SI)																
Western	1	1	1	1	γ_8	-	-	-	-	-	-	-	-	-	-	-
Eastern WFG	-	-	γ_7	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
North	-	-	-	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_5	1	γ_6	1	1	1
(d) Hypothesis 6b (no WFG feeding aggregation)																
Western	1	1	1	1	1	1	-	-	1	-	γ_4	-	-	1	1	1
Eastern North	-	-	-	-	-	-	1	1	1	1	1	-	1	1	1	1
PCFG	-	-	-	-	-	-	χ_1	γ_2	1	γ_3	γ_5	1	γ_6	1	1	1

D. IMMIGRATION (DISPERSAL)

The numbers dispersing into feeding aggregation j of breeding stock i, include contributions from pulse migration as well as diffusive dispersal:

$$I_{t,a}^{s,j,i} = \sum_k \delta^{k,j,i} \tilde{N}_{t,a}^{s,i,k} \left(\frac{N_t^{f,i,k}}{N_{-\infty}^{f,i,k}}\right)^{\lambda} - \sum_k \delta^{j,k,i} \tilde{N}_{t,a}^{s,i,j} \left(\frac{N_t^{f,i,j}}{N_{-\infty}^{f,i,j}}\right)^{\lambda} + \sum_{k\neq j} \Omega_y^{k,j,i} \frac{\tilde{N}_{t,a}^{s,i,k}}{\sum_{a=1}^{x}(\tilde{N}_{t,a}^{m,i,k} + \tilde{N}_{t,a}^{f,i,k})} - \sum_{k\neq j} \Omega_y^{j,k,i} \frac{\tilde{N}_{t,a}^{s,i,j}}{\sum_{a=1}^{x}(\tilde{N}_{t,a}^{m,i,j} + \tilde{N}_{t,a}^{f,i,j})} \tag{D.1}$$

where

$\delta^{k,j,i}$ is the rate of dispersal from feeding aggregation k to feeding aggregation j of breeding stock i;

λ is a factor to allow for density-dependence in the dispersal rate (set to 2);

$\Omega_y^{k,j,i}$ is the number of animals that disperse during year y from feeding aggregation k to feeding aggregation j of breeding stock in a pulse; and

$$\tilde{N}_{t,a}^{s,i,k} = (N_{t,a}^{s,i,k} - C_{t,a}^{s,i,k})\, S_a$$

E. ANTHROPOGENIC REMOVALS

The catch by feeding aggregation is generally determined by apportioning the catches by fleet[5], taking account of mixing (i.e. exposure to harvesting) matrices, according to:

$$C_{t,a}^{m/f,i,j} = \sum_k C_t^{m/f,k} \frac{\alpha_a^k X^{A_k,i,j} N_{t,a}^{m/f,i,j}}{\sum_{i,j,a} \alpha_a^k X^{A_k,i,j} N_{t,a}^{m/f,i,j}} \tag{E.1}$$

where

$C_t^{m/f,k}$ is the catch of males/females caught by fleet k during year t;

A_k is the sub-area in which fleet k operates; and

α_a^k is the relative vulnerability of animals of age a to harvest by the fleets that operate in sub-area k.

The incidental catches (bycatch as defined above) by feeding ground are computed using the equation:

[5]A fleet is the combination of a fishery sector (commercial/aboriginal) and the feeding ground in which the catch is taken.

$$C_t^{\mathrm{I},A} = \lambda^A E_t^A \sum_{i,j,a,m/f} \tilde{\alpha}_a X^{A,i,j} N_{t,a}^{m/f,i,j} \tag{E.2}$$

where

$C_t^{\mathrm{I}/s,A}$ is the incidental catch of animals of sex s in feeding ground A during year t;

E_t^A is a measure of the effort in feeding ground A during year t;

λ^A is the catchability coefficient for bycatch; and

$\tilde{\alpha}_a$ is 1 for ages 0 to 5 and 0 for all other ages (IWC, 2016).

The incidental catches are allocated to feeding aggregation, sex and age using the formula:

$$C_{t,a}^{I,m/f,i,j} = \sum_A C_t^{I,A} \frac{\tilde{\alpha}_a X^{A,i,j} N_{t,a}^{m/f,i,j}}{\sum_{i,j,m/f,a} \tilde{\alpha}_a X^{A,i,j} N_{t,a}^{m/f,i,j}} \tag{E.3}$$

F. INITIALISING THE PARAMETER VECTOR

The numbers at age in the pristine population are given by:

$$\begin{aligned} N_{-\infty,a}^{m/f,i,j} &= 0.5\, N_{-\infty,0}^{i,j} \prod_{a'=0}^{a-1} S_{a'} && \text{if } a < x \\ N_{-\infty,x}^{m/f,i,j} &= 0.5\, N_{-\infty,0}^{i,j} \prod_{a'=0}^{x-1} S_{a'} / (1 - S_x) && \text{if } a = x \end{aligned} \tag{F.1}$$

The value for $N_{-\infty,0}^{i,j}$ is determined from the value for the pre-exploitation size of the 1+ component of feeding aggregation j of breeding stock i using the equation:

$$N_{-\infty,0}^{m,i,j} = K^{1+,i,j} \Bigg/ \left(\sum_{a=1}^{x-1} \left(\prod_{a'=0}^{a-1} S_{a'} \right) + \frac{1}{1 - S_x} \prod_{a'=0}^{x-1} S_{a'} \right) \tag{F.2}$$

where $K^{1+,i,j}$ is the carrying capacity (in terms of the 1+ population size) for feeding aggregation j of breeding stock i:

$$K^{1+,i,j} = \sum_{a=1}^{x} (N_{-\infty,a}^{m,i,j} + N_{-\infty,a}^{f,i,j}) \tag{F.3}$$

$N_{-\infty,a}^{m/f,i,j}$ is the number of animals of age a that would be in feeding aggregation j of breeding stock i in the pristine population.

The model is based on the assumption that the age-structure at the start of year τ is stable rather than that the population was at its pre-exploitation equilibrium size at some much earlier year. The determination of the age-structure at the start of year τ involves specifying the effective 'rate of increase', γ, that applies to each age-class. There are two components contributing to γ, one relating to the overall population rate of increase (γ^+) and the other to the exploitation rate due to all forms of anthropogenic removal. Under the assumption of knife-edge recruitment to the fishery at age a_r, only the γ^+ component (assumed to be zero following Punt and Butterworth, 2002) applies to ages a of a_r or less. The number of animals of age a at the start of year τ relative to the number of calves at that time, $N_{t,a}^*$, is therefore given by the equation:

$$N_{\tau,a}^* = \begin{cases} 1 & \text{if } a = 0 \\ N_{\tau,a-1}^* S_{a-1} & \text{if } a \le a_r \\ N_{\tau,a-1}^* S_{a-1} (1-\gamma) & \text{if } a_r < a < x \\ N_{\tau,x-1}^* S_{x-1} (1-\gamma) / (1 - S_x (1-\gamma)) & \text{if } a = x \end{cases} \tag{F.4}$$

where B_τ is the number of calves in year τ and is derived directly from equations C.1 and C.6.

$$B_\tau = \left(1 - \left[1/(N_\tau^f b_K) - 1\right] / A\right)^{1/z} \frac{K^{1+}}{N_\tau^{1+,*}} \tag{F.5}$$

The effective rate of increase, γ, is selected so that if the population dynamics model is projected from year τ to a year Ψ, the size of the 1+ component of the population in a reference year Ψ equals a value, P_Ψ.

G. CONDITIONING

The parameters of the model are: (a) the carrying capacity of each stock; (b) the population (expressed relative to carrying capacity) for each stock at the start of 1930; (c) MSYR by stock; (d) annual survival under 'normal' conditions; (e) maturity as a function of age; (f) the impact of the mortality event in the eastern Pacific in 1999 and 2000; (g) selectivity; (h) the rate of dispersal between the North and PCFG feeding aggregations; (i) the parameters of the mixing matrices; (j) the catchability coefficients that determine bycatch by sub-area; and (k) the extent of additional variation for each abundance index. Some of these parameters are pre-specified:

(1) MSYR (except for trials 14-20);
(2) annual survival under 'normal' conditions (=$e^{-0.05}$);
(3) maturity as a function of age (a logistic function of age, with an age-at-50%-first-parturition of 8 years and a minimum age-at-first parturition of 3 years); and
(4) selectivity (knife-edged at age 1).

Under the assumption that the estimates of abundance for a feeding ground (see Table 2) are log-normally distributed, the negative of the logarithm of the likelihood function is given by:

$$-\ell nL = \ell n\sqrt{\mathrm{Det}[V]} + 0.5\sum_k (\ell\,\mathrm{n}\,\underline{N}^{A,obs} - \ell\,\mathrm{n}\,\underline{N}^{A})[V^{-1}](\ell\,\mathrm{n}\,\underline{N}^{A,obs} - \ell\,\mathrm{n}\,\underline{N}^{A})^T \qquad \text{(G.1)}$$

where

$N_t^{A,\mathrm{obs}}$ is the survey estimate of abundance for sub-area A during year t; and

V is the sum of the variance-covariance matrix for the abundance estimates plus an additional variance term (assumed to be independent of year).

The data on the proportion of each stock (see Table 3) in each feeding ground is modelled under the assumption that the proportions are normally distributed, i.e.:

$$-\ell nL = \sum_i \sum_A \sum_t \frac{1}{2(\tau_t^{i,A})^2}(p_t^{i,A} - p_t^{i,A,\mathrm{obs}})^2 \qquad \text{(G.2)}$$

where

$p_t^{i,A}$ is the model-estimate of the proportion of the animals in feeding ground A that are from feeding aggregation i of the Eastern breeding stock;

$p_t^{i,A,\mathrm{obs}}$ is the observed proportion of animals in in feeding ground A that are from feeding aggregation i of the Eastern breeding stock; and

$\tau_t^{i,A}$ is the standard error of $p_t^{i,A,\mathrm{obs}}$.

The (non-zero) bycatches by sub-area (see Table 4) are assumed to be log-normally distributed, and the model is fitted to the average bycatch by sub-area over a pre-specified set of years, i.e.:

$$-\ell \mathrm{n}L = \sum_A \frac{1}{2\sigma_{BC}^2}\left(\ell \mathrm{n} C^{I,A,\mathrm{obs}} - \ell \mathrm{n}\hat{\bar{C}}^{I,A}\right)^2 \qquad \text{(G.3)}$$

where

$C^{I,A,\mathrm{obs}}$ is the observed average annual bycatch from feeding ground A over the pre-specified period;

$\hat{\bar{C}}^{I,A}$ is the average over this period of the model-estimate of the bycatch from feeding ground A; and

σ_{BC} is the standard error of the logarithms of the observed bycatches.

A penalty is imposed on the average number of animals moving permanently from the 'north' feeding aggregation into the 'PCFG' feeding aggregation between 2001 and 2008, i.e.:

$$-\ell nL = \frac{1}{2\sigma_I^2}\left(\tilde{I} - \frac{\delta^{\mathrm{m/f,north,West}}}{8}\sum_{t=2001}^{2008}\sum_{s=m/f}\sum_{a=1}^{x}\tilde{N}_{t,a}^{s,\mathrm{East,north}}\right)^2 \qquad \text{(G.4)}$$

where

$\tilde{I}$ is the pre-specified average number of immigrants into the PCFG feeding aggregation from the 'North' feeding aggregation; and

σ_I is a weighting factor.

Table 2a

Indices of 1+ abundance for the Sakhalin sub-area based on Bayesian population dynamics model (J.G. Cooke, pers. commn).

Year	Estimate	CV
1995	68.9	0.0567
1996	71.1	0.0513
1997	76.3	0.0367
1998	78.7	0.0338
1999	87.2	0.0240
2000	87.7	0.0235
2001	92.3	0.0190
2002	97.2	0.0172
2003	104.8	0.0170
2004	114.6	0.0175
2005	120.2	0.0191
2006	126.2	0.0181
2007	128.0	0.0192
2008	128.8	0.0215
2009	131.1	0.0232
2010	137.2	0.0238
2011	141.1	0.0240
2012	152.0	0.0282
2013	155.6	0.0333
2014	164.3	0.0390

Table 2b

Estimates of absolute abundance (with associated standard errors) for the eastern North Pacific stock of gray whales based on shore counts (source: 1967/78-2006/07: Laake *et al.*, 2012; 2006/07-2010/11: Durban *et al.*, In press).

Year	Estimate	CV	Year	Estimate	CV
1967/68	13,426	0.094	1985/86	22,921	0.081
1968/69	14,548	0.080	1987/88	26,916	0.058
1969/70	14,553	0.083	1992/93	15,762	0.067
1970/71	12,771	0.081	1993/94	20,103	0.055
1971/72	11,079	0.092	1995/96	20,944	0.061
1972/73	17,365	0.079	1997/98	21,135	0.068
1973/74	17,375	0.082	2000/01	16,369	0.061
1974/75	15,290	0.084	2001/02	16,033	0.069
1975/76	17,564	0.086	2006/07	19,126	0.071
1976/77	18,377	0.080	2006/07	20,750	0.060
1977/78	19,538	0.088	2007/08	17,820	0.054
1978/79	15,384	0.080	2009/10	21,210	0.046
1979/80	19,763	0.083	2010/11	20,990	0.044
1984/85	23,499	0.089			

Table 2c

Estimates of absolute abundance (with associated CVs) for the PCFG feeding aggregation based on mark-recapture analysis (source: J. Laake, pers. commn).

Year	Estimate	CV	Year	Estimate	CV
1998	126	0.086	2006	200	0.106
1999	147	0.102	2007	193	0.133
2000	149	0.101	2008	207	0.088
2001	181	0.077	2009	206	0.098
2002	198	0.064	2010	194	0.094
2003	210	0.086	2011	197	0.080
2004	218	0.078	2012	209	0.073
2005	218	0.120			

Table 3

Data on mixing proportions (definite and likely matches/non-matches only) to be used when conditioning the models.

Area	Year	Stock concerned	Estimate (assumed SD)
EJPJ	2007[d]	WFG	1 (0.1)
EJPJ	2012[d]	Western	1 (0.1)
EJPJ	2015[d]	WFG	1 (0.1)
EJPJ	2005[l]	Western	1 (0.1)
EJPJ	2007[l]	Western	1 (0.1)
SI	2012	Western	0.40[a] (0.1)
SEA (Jun.-Nov.)	2012	PCFG	0.559 (0.15)
BCNC (Jun.-Nov.)	2012	PCFG	0.951 (0.05)
BCNC (Dec.-May)	2012	WFG	0.002 (0.05)
BCNC (Dec.-May)	2012	PCFG	0.339 (0.15)
CA (Jun.-Nov.)	2012	PCFG	0.472 (0.15)

[a]Stock structure hypothesis 5a only (changed in sensitivity analysis).
[d]Definite; [l]Likely.

Table 4
Scenarios regarding bycatch.

Sub-area	Years	Numbers dead	Dead and serious injury	Numbers dead x 4	Numbers dead x 8
VSC	1990-2014	1/25	??	4/25	8/25
EJPJ	1990-2014	4/25	??	16/25	32/25
SI	1997-2014	1.5/18	??	6/18	12/18
BSCS					
SEA (Jun.-Nov.)					
SEA (Dec.-May)					
BCNC (Jun.-Nov.)					
BCNC (Dec.-May)					
CA (Jun.-Nov.)					
CA (Dec.-May)					

H. QUANTIFYING UNCERTAINTY USING BOOTSTRAP

A bootstrap procedure is used to quantify uncertainty for a given model specification. Each bootstrap replicate involves:

(1) generating pseudo time-series of abundance estimates based on the assumption that the abundance estimates are log-normally distributed with means and variance-covariance matrices given by the observed abundance estimates and the reported variance-covariance matrices;

(2) generating pseudo mixing proportions from beta distributions with means and CVs given by the observed means and CVs;

(3) generating pseudo bycatch rates by feeding ground from log-normal distributions with means of $C^{I,A,\text{obs}}$ and a log standard error of σ_{BC}; and

(4) generating a pseudo immigration rate from the 'North' into the PCFG feeding aggregation based on a normal distribution (truncated at zero) with mean $\tilde{I}$ and standard error σ_I.

I. GENERATION OF DATA

The actual historical estimates of absolute abundance (and their associated CVs) provided to the *Strike Limit Algorithms* are listed in Table 2. The future estimates of abundance for sub-areas BCNC-3 and CA-3 (say sub-area *K*) are generated using the formula:

$$\hat{P} = PYw / P^* \beta^2 Yw \tag{F.1}$$

where:

Y is a lognormal random variable Y=e$^{\varepsilon}$ where $\varepsilon \sim N(0;\sigma_\varepsilon^2)$ and $\sigma_\varepsilon^2 = \ell n(1+\alpha^2)$;

w is a Poisson random variable with $E(w) = \text{var}(w) = \mu = (P / P^*) / \beta^2$, *Y* and *w* are independent;

P is the current total (1+) population size in survey area *K*:

$$P = P_t^K = \sum_i \sum_j \sum_g \sum_{a\geq 1} N_{t,a}^{g,i,j} \tag{F.2}$$

*P** is the reference population level, and is equal to the total (1+) population size in the survey area prior to the commencement of exploitation in the feeding ground for which an abundance estimate is to be generated. For consistency with the first-stage screening trials for a single stock (IWC, 1991; 1993), the ratio $\alpha^2 : \beta^2 = 0.12 : 0.025$, so that $CV^2(\hat{P}) = \tau\,(0.12 + 0.025\, P^*/P)$. If $\overline{CV}$ is the target CV then $\tau = \overline{CV^2}/(0.12 + 0.025P_{\text{ref}}/P^*)$ where P_{ref} is the population size in a reference year.

An estimate of the *CV* is generated for each estimate of abundance:

$$CV(\hat{P})^2_{\text{est}} = \sigma^2 \chi^2 / n \tag{F.3}$$

where $\sigma^2 = \ell n(1+\alpha^2 + \beta^2 P^* / \hat{P})$, and χ is a random number from a Chi-square distribution with *n* degrees of freedom (where *n*=10 as used for NP minke trials; IWC, 2004).

J. TRIALS

The factors included in the trials are listed in Table 5 and the trials in Table 6.

Table 5

Factors considered in the model scenarios. The **bolded** values are the base-levels.

Factor	Levels
Model fitting related	
Stock hypothesis	**3a, 3e, 5a**
Proportion of 'Western' stock in Sakhalin sub-area	**0** (stock hypotheses 3a, 3e), **0.33** (stock hypothesis 5a), 0.70
$MSYR_{1+}$ (western)	As for WFG
$MSYR_{1+}$ (north)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (WFG)	**4.5%**, 5.5%, Estimated (common); estimate (separately)
$MSYR_{1+}$ (PCFG)	2%, **4.5%**, Estimated (common); estimate (separately)
Matches	Definite; Definite+Likely (Table 2)
Immigration into the PCFG	**0, 2,** 4
Bycatches and ship strikes	Numbers dead, M/SI, numbers dead x 4; x numbers dead x 10
Pulse migrations into the PCFG	10, **20,** 30
Bycatch off Sakhalin	**1.5,** 3
Projection-related	
Northern need in final year (from 150 in 2014)	**340**, 530
Struck and lost rate	25%, **50%**, 75%
Future effort	**Constant,** Increase by 100% over 100 years
Probability of mismatching a north whale, p_1	**0.01**
Probability of mismatching a PCFG, p_2	0.05 (trials)
PCFG harvest month	**Migratory**

K. MANAGEMENT OPTIONS

The strike limits for the BSCS feeding ground are based on the *Gray Whale SLA* (IWC, 2005), while the strike limits for the BCNC feeding ground are based on 'research with variant' (*SLA* variant 1) option (IWC, 2013). The steps below show how the proposed Makah Management plan operates. Variant 1 would have steps (1), (3), and (4) but not (2). Variant 2 would have (2) (3) and (4). Furthermore, variant 1 has hunting from December-May.

(1) Compute the ABL (Allowable Bycatch Limit of PCFG whales)
  - (a) Strike an animal.
  - (b) If the animal is struck-and lost in December-April[6]:
  - (c) if the total number of struck and lost animals is 3, stop the hunt.
  - (d) if the total number of struck animals equals the need of 7 stop the hunt.
  - (e) go to step (2).

(2) If the animal is struck-and lost in May:
  - (a) add one to the number of whales counted towards the ABL.
  - (b) if the ABL is reached; stop the hunt.
  - (c) if the total number of struck and lost animals is 3, stop the hunt.
  - (d) if the total number of struck animals equals the need of 7; stop the hunt.
  - (e) go to step (2).

(3) If the animal is landed and is matched against the catalogue[7]:
  - (a) add one to the number of whales counted towards the ABL.
  - (b) if the ABL is reached; stop the hunt.
  - (c) if the total number of landed whales equals 5; stop the hunt.
  - (d) if the total number of struck animals equals the need of 7; stop the hunt.
  - (e) if the number of landed whales for the current five-year block equals 20; stop the hunt.
  - (f) go to step (2).

(4) If the animal is landed and does not match any whale in the catalogue:
  - (a) if the total number of landed whales equals 5; stop the hunt.
  - (b) if the total number of struck animals equals the need of 7; stop the hunt.
  - (c) if the number of landed whales for the current five-year block equals 20; stop the hunt.
  - (d) go to step (2).

Removals due to bycatch are based on the scenarios regarding future trends in effort. Table 5 lists the factors considered in the projections.

[6]Whether a whale is struck and lost is determined from a Bernoulli trial with probability 0.5 (base-case).
[7]PCFG whales are mismatched as north stock whales with probability p_2 while north stock whales are matched to the catalogue with probability p_1.

Table 6
The model specifications.

Trial	Description/stock hypothesis	PCFG in BSCS	$MSYR_{1+}$ North	$MSYR_{1+}$ PCFG	$MSYR_{1+}$ WFG	% Western in Sakhalin	PCFG immigration
1A	Reference 3a	No	4.5%	4.5%	4.5%	0	2
1B	Reference 3e	No	4.5%	4.5%	4.5%	0	2
1C	Reference 5a	No	4.5%	4.5%	4.5%	0.33	2
2A	Lower MSYR PCFG 3a	No	**4.5%**	**2%**	**4.5%**	0	2
2B	Lower MSYR PCFG 3e	No	**4.5%**	**2%**	**4.5%**	0	2
2C	Lower MSYR PCFG 5a	No	**4.5%**	**2%**	**4.5%**	0.33	2
3A	Higher MSYR WFG and North 3a	No	**5.5%**	**5.5%**	**4.5%**	0	2
3B	Higher MSYR WFG and North 3e	No	**5.5%**	**5.5%**	**4.5%**	0	2
3C	Higher MSYR WFG and North 5a	No	**5.5%**	**5.5%**	**4.5%**	0.4	2
4C	Higher Western breeding stock in Sakhalin 5a	No	4.5%	4.5%	4.5%	**0.7**	2
5A	Alternative matches 3a	No	4.5%	4.5%	4.5%	0	2
5B	Alternative matches 3e	No	4.5%	4.5%	4.5%	0	2
5C	Alternative matches 5a	No	4.5%	4.5%	4.5%	0.33	2
6A	Lower PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**0**
6B	Lower PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**0**
6C	Lower PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**0**
7A	Higher PCFG Immigration 3a	No	4.5%	4.5%	4.5%	0	**4**
7B	Higher PCFG Immigration 3e	No	4.5%	4.5%	4.5%	0	**4**
7C	Higher PCFG Immigration 5a	No	4.5%	4.5%	4.5%	0.33	**4**
8A	Lower Pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2
8B	Lower Pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2
8C	Lower Pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2
9A	Higher pulse into PCFG 3a	No	4.5%	4.5%	4.5%	0	2
9B	Higher pulse into PCFG 3e	No	4.5%	4.5%	4.5%	0	2
9C	Higher pulse into PCFG 5a	No	4.5%	4.5%	4.5%	0.33	2
10A	Bycatch x 4 3a	No	4.5%	4.5%	4.5%	0	2
10B	Bycatch x 4 3e	No	4.5%	4.5%	4.5%	0	2
10C	Bycatch x 4 5a	No	4.5%	4.5%	4.5%	0.33	2
11A	Bycatch x 10 3a	No	4.5%	4.5%	4.5%	0	2
11B	Bycatch x 10 3e	No	4.5%	4.5%	4.5%	0	2
11C	Bycatch x 10 5a	No	4.5%	4.5%	4.5%	0.33	2
12A	Bycatch = 3 in SI 3a	No	4.5%	4.5%	4.5%	0	2
12B	Bycatch = 3 in SI 3e	No	4.5%	4.5%	4.5%	0	2
12C	Bycatch = 3 in SI 5a	No	4.5%	4.5%	4.5%	0.33	2
13A	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2
13B	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0	2
13C	PCFG feeding aggregation in BSCS	**Yes**	4.5%	4.5%	4.5%	0.33	2
14A	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2
14B	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0	2
14C	$MSYR_{1+}$ estimated (common over FA) 3a	No		**Estimated**		0.33	2
15A	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
15B	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
15C	$MSYR_{1+}$ estimated (separate by FA) 3a	No	**Estimated**	**Estimated**	**Estimated**	0.33	2
16A	Lower PCFG immigration and higher bycatch 3a	No	4.5%	4.5%	4.5%	0	**0**
16B	Lower PCFG immigration and higher bycatch 3e	No	4.5%	4.5%	4.5%	0	**0**
16C	Lower PCFG immigration and higher bycatch 5a	No	4.5%	4.5%	4.5%	0.33	**0**
17A	MSYR estimated and lower pulse 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
17B	MSYR estimated and lower pulse 3e	No	**Estimated**	**Estimated**	**Estimated**	0	2
17C	MSYR estimated and lower pulse 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	2
18A	MSYR estimated and higher pulse 3a	No	**Estimated**	**Estimated**	**Estimated**	0	2
18B	MSYR estimated and higher pulse 3e	No	**Estimated**	**Estimated**	**Estimated**	0	2
18C	MSYR estimated and higher pulse 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	2
19A	MSYR estimated and higher immigration 3a	No	**Estimated**	**Estimated**	**Estimated**	0	**4**
19B	MSYR estimated and higher immigration 3e	No	**Estimated**	**Estimated**	**Estimated**	0	**4**
19C	MSYR estimated and higher immigration 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	**4**
20A	MSYR estimated and much higher immigration 3a	No	**Estimated**	**Estimated**	**Estimated**	0	**8**
20B	MSYR estimated and much higher immigration 3e	No	**Estimated**	**Estimated**	**Estimated**	0	**8**
20C	MSYR estimated and much higher immigration 5a	No	**Estimated**	**Estimated**	**Estimated**	0.33	**8**

L. OUTPUT STATISTICS

The population-size statistics are produced for each breeding stock/feeding aggregation, while the removal-related statistics are for each sub-area.

L.1 Risk

D1. Final depletion: P_T/K.

D2. Lowest depletion: min $(P_t/)$: t=0,1,…,T.

D3. Plots of $\{P_{t[x]}$: t=0,1,…,T where $P_{t[x]}$ is the xth percentile of the distribution of P_i. Results are presented for x=5 and x=50.

L.2 Removal-related

R1. Plots of strikes by year for simulations 1-100.

R2. Plots of landed whales by year for simulations 1-100.

R3. Plots of incidental catches by year for simulations 1-100.

R4. A table for the proportion of catch of WFG whales by sub-area (20 and 100 years).

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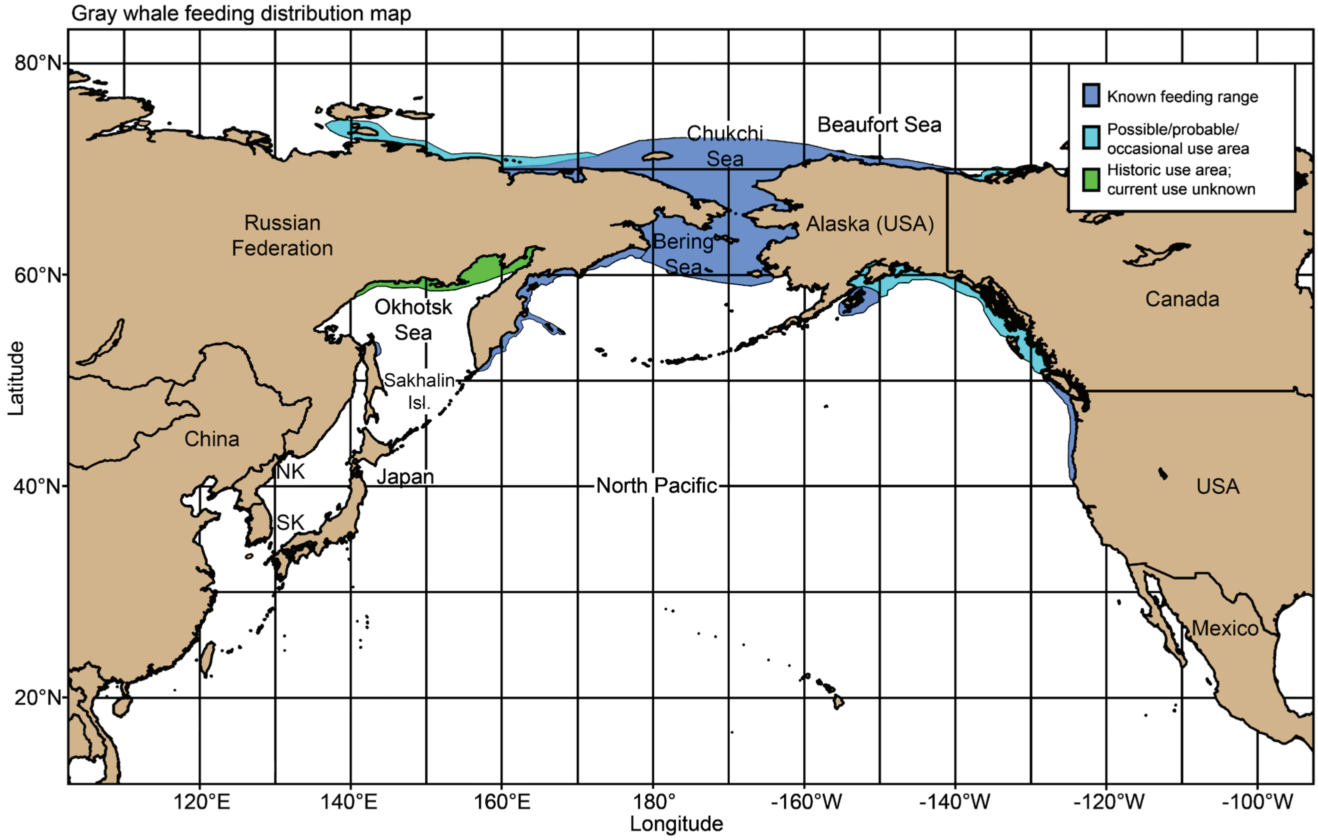
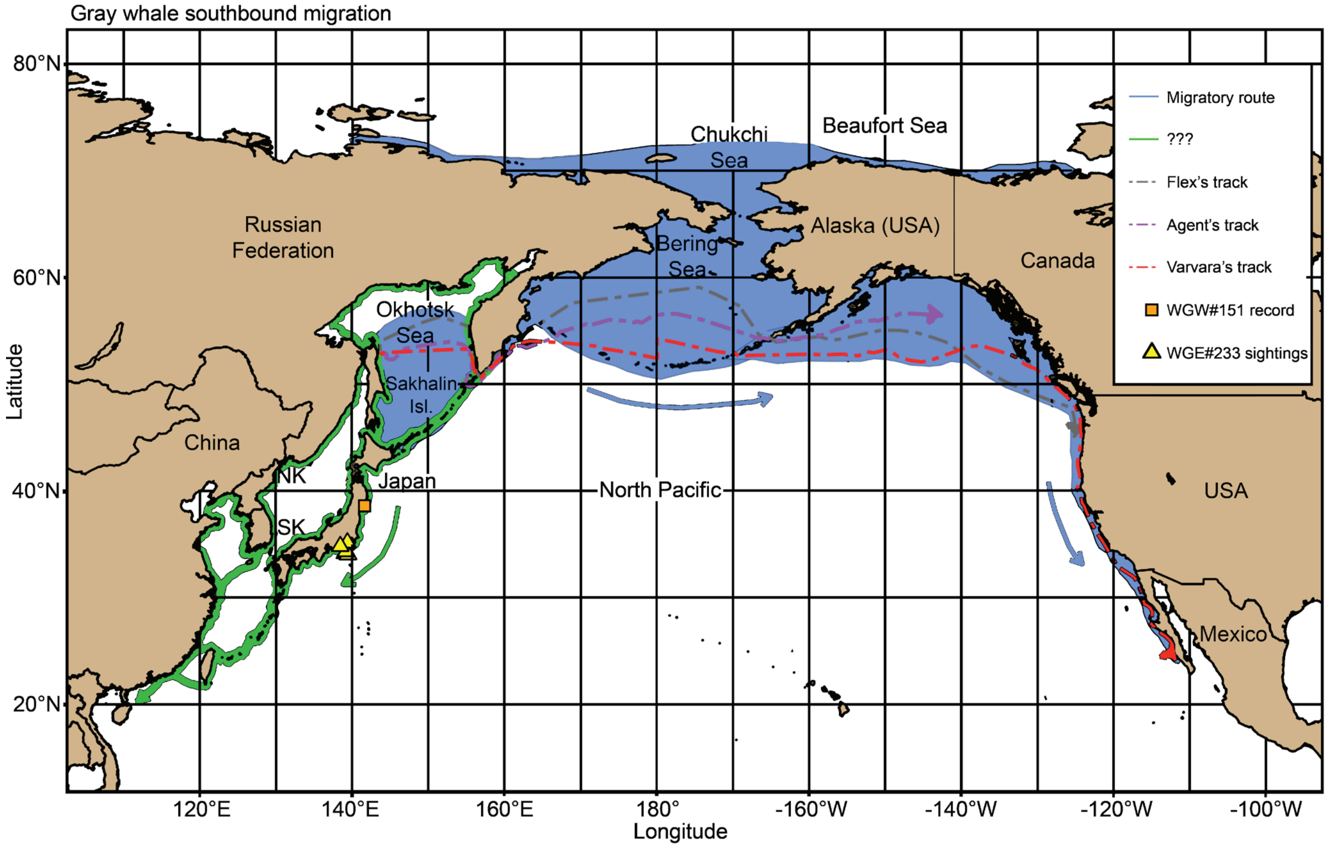
Annex G

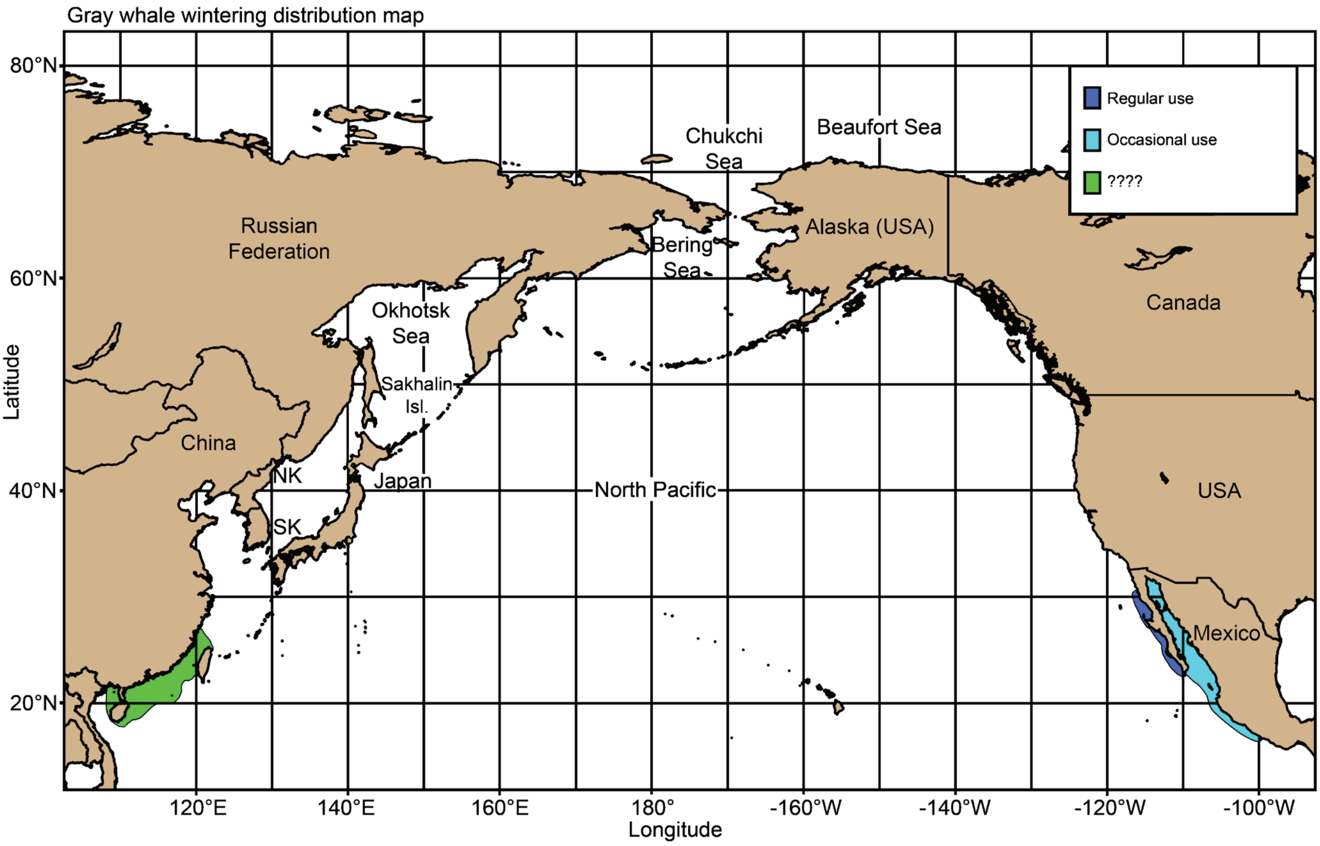
Schematic Summarising Present Knowledge of the Distribution of Gray Whales in the North Pacific on a Seasonal Basis

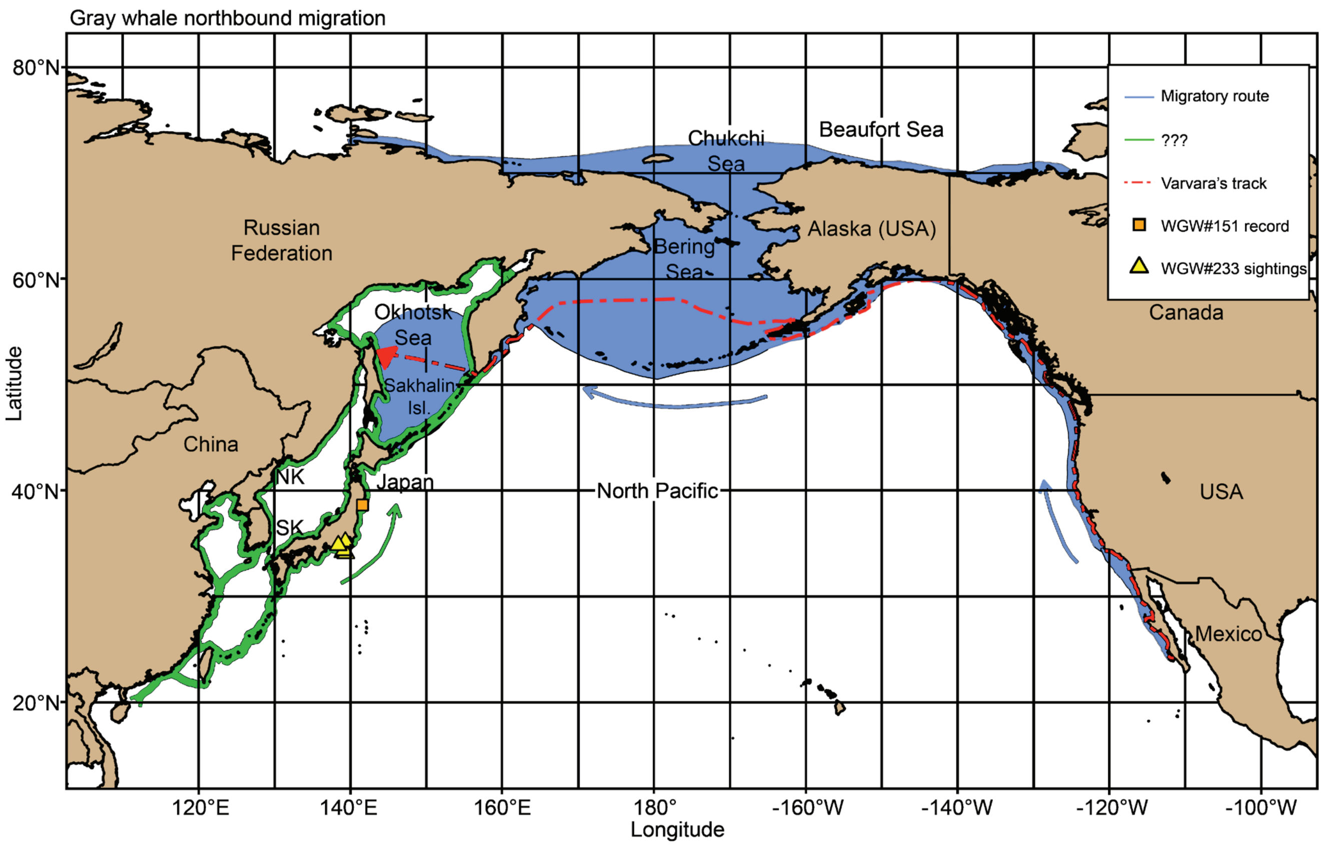
Gray whale feeding distribution map



Gray whale southbound migration







This four-panel map is a schematic summarising present knowledge of the distribution of gray whales in the North Pacific on a seasonal basis: the summer feeding period (a), the period of southward migration (and breeding) in late autumn (b), the winter calving, early calf rearing and fasting season (c), and the period of northward migration in spring (d). The maps also include all known reports of gray whales in the western North Pacific since 1995 (for details see Annex E).