Annex F

Summary of Gray Whale Stock Structure Hypotheses

At the last Rangewide Workshop on the Population Structure and Status of Gray Whales in the North Pacific (IWC, 2019), it was agreed that stock hypotheses 3a and 5a would form the references for the analyses as they appear to be most plausible, while trials would also be conducted for stock hypotheses 3b, 3c, 3e and 6b.

At SC68B, new information pertaining to the stock structure of gray whales was reviewed (SC/68B/SDDNA/01-03, SC/68B/ASI/01, Brykov *et al.* (2019). In light of this and previously reviewed information, the Committee agreed that existing hypothesis 4a should be given high plausibility and existing hypothesis 4b should be given medium plausibility (see Item 10.4.1). In addition, the Committee agreed that additional medium plausibility hypotheses should be added that are the same as 3c and 3e but incorporate a lack of random mating between the Western Feeding Group whales and other whales considered part of the Eastern Breeding Stock under hypothesis 3. It was noted, however, that hypothesis 3 and its variants and hypothesis 4 and its variants are functionally the same and thus elevating the plausibility of Hypothesis 4a and its variants (4b and the newly added 4c and 4e) does not entail adding additional trials for testing under the gray whale *Implementation Review*.

It was further noted at SC68B some of the terminology used to describe the hypotheses needs to be clarified and there is a need to assess if further changes are needed to ensure that all plausible scenarios and their respective plausibilities are represented. An intersessional correspondence group was formed to complete these tasks and report on their findings at SC68C (see Item 10.7).

TERMINOLOGY (IWC, 2018)

Feeding groups or aggregations: There are up to three feeding groups or aggregations. There is dispersal between the Pacific Coast Feeding Group (PCFG) and the North Feeding Group (NFG). The dynamics of the Western Feeding Group (WFG) are defined within each of the hypotheses; no permanent movement of animals from the NFG or PCFG to the WFG is modelled.

Table 1

Feeding groups.

Name	Abbreviation	Definition (may vary with hypothesis)
Western Feeding Group	WFG	Animals that feed off Sakhalin Island* according to photo-identification data.
Pacific Coast Feeding Group	PCFG	Animals that are observed in the feeding season (June to November) in the PCFG area (41°N to 52°N, excluding Puget Sound) in more than one year according to photo-identification data (IWC, 2015).
North Feeding Group	NFG	Animals found in other feeding areas (and for which there is relatively little photo-ID and genetic information).

*May need revising with regard to southern Kamchatka animals given Cooke *et al.* (2017).

Breeding stocks: There are up to three extant breeding stocks. These breeding stocks are the Western (WBS) and eastern (EBS) stocks, and a third stock comprised of WFG whales that interbreed largely with each other while migrating to the Mexican wintering ground (hypothesis 4 and its variants).

Sub-areas: The model includes 11 geographical sub-areas that are used to explain the movements of gray whales (breeding stocks and feeding groups) in the North Pacific and two 'latent sub-areas' used to link model predictions to observed indices of abundance.

Table 2

Sub-areas.

Sub-area	Abbreviation	Sub-area	Abbreviation
Vietnam-South China Sea	VSC	Southeast Alaska	SEA
Korea and western side of the Sea of Japan	KWJ	British Columbia to Northern California	BCNC
Eastern side of the Sea of Japan and the Pacific coast of Japan	EJPJ	California	CA
Northeastern Sakhalin Island	SI	Mexico	M
Southern Kamchatka and Northern Kuril Islands*	SKNK	Latent subarea	Calif-3
Areas of the Okhotsk Sea not otherwise specified	OS	Latent subarea	BC-BCA-3
Northern Bering and Chukchi Sea	BSCS		

*replaced the old East Kamchatka and Kuril Islands sub-area to recognise the information from telemetry and photo-ID.

Table 3 [updated from Table 6, IWC (2018)].

A summary of the stock structure hypotheses and their status after consideration at SC68B.

Description	Plausibility	Comment
(3) Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating		
(a) A single breeding stock (EBS) exists. The EBS includes three feeding groups: NFG, PCFG, WFG. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG. Although two breeding stocks (WBS and EBS) may once have existed, the WBS is assumed to have been extirpated.	High	
(b) The EBS is as described in 3a, except that NFG whales do not feed off SKNK. In addition, a WBS exists that overwinters in VSC and feeds in the OS (but not SI) and SKNK. Thus SKNK is used by both the WFG whales and the whales of the WBS.	Medium	Originally considered there to be few or no data to assess plausibility (IWC, 2015), but availability of abundance estimates for combined SKNK + SI (Cooke *et al.*, 2017) made feasible to assess.
(c) Same as 3a except that WFG whales migrating from SI to M occasionally travel through BSCS.	Medium	Sensitivity test
(e) Same as 3a except that a WBS exists that feeds in the OS (but not SI), EJPJ, and KWJ and overwinters in VSC. This hypothesis is also similar to 3b, with the exception that SKNK region is not used regularly by whales part of the WBS.	Medium	Originally ranked as high (IWC, 2015). At the SC in 2018, the Workshop reviewed Scordino and Bickham (2018), which argues that if a WBS was extent it would be unlikely that they do not feed off SI. The Workshop agreed that the plausibility of Hypothesis 3e would be changed to medium (sensitivity test).
(4) Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating		
(a) Two breeding stocks exist and overwinter in M. One breeding stock includes NFG and PCFG, and the second breeding stock includes WFG whales that mate largely with each other while migrating to M. SKNK is used by some whales that belong to the breeding stock comprised of WFG whales and some whales that belong to the NFG. Although a third breeding stock (the WBS) may once have existed, the WBS is assumed to have been extirpated.	High	Initially regarded as low priority because it is represented in the same way as other hypotheses in modeling (IWC, 2015). After re-evaluation at SC68B, the SDDNA WG advised that this hypothesis be ranked as high plausibility based on genetic evidence that WFG whales do not mate at random with NFG and PCFG whales (see report Item 10.4.1).
(b) Same as 3b except that a third breeding stock comprised of WFG whales that largely breed with each other while on migration to M exists.	Medium	Initially regarded as low priority because it is represented in the same way as other hypotheses in modeling (IWC, 2015). After re-evaluation at SC68B, the SDDNA WG advised that this hypothesis be ranked as medium plausibility (in accordance with the plausibility of 3b) after raising 3a to high plausibility.
(c) Same as 3c except that a second breeding stock comprised of WFG whales that largely breed with each other while on migration to M exists. Whales that are part of this second breeding stock occasionally travel through BSCS.	Medium	Added as a medium plausibility hypothesis (in accordance with the plausibility of 3c) after the status of hypothesis 4a was raised to high upon re-evaluation by the SDDNA WG at SC68B.
(e) Same as 3e except that a third breeding stock comprised of WFG whales that largely breed with each other while on migration to M exists. A WBS exists that feeds in the OS (but not SI), EJPJ, and KWJ and overwinters in VSC	Medium	Added as a medium plausibility hypothesis (in accordance with the plausibility of 3e) after the status of hypothesis 4a was raised to high upon re-evaluation by the SDDNA WG at SC68B.
(5) Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, random mating		
(a) Two breeding stocks exist: EBS and WBS. The EBS includes three feeding groups: PCFG, North, and the WFG that feeds off SI. The WBS whales feed in SI, OS, and SKNK and then migrate to VSC to overwinter. SKNK is used by the WFG, the NFG, and the feeding whales that are part of the WBS.	High	
(6) Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds without fidelity, random mating		
(b) Two breeding stocks (WBS and EBS) and three feeding groups (WFG, NFG, and PCFG) exist. SKNK is used by both the WFG and NFG. The WBS stock includes WFG whales, while the EBS stock includes NFG and PCFG whales. WBS whales use both wintering grounds (M and VSC). WBS individuals do not show fidelity for a particular wintering ground but do breed largely with each other during migration. EBS whales overwinter in M.[1]	Medium	Initially considered to be of low priority because modelling framework represented in the same way as other hypotheses (IWC, 2015); when revisited, the Workshop determined that this hypothesis does differ from 5a, in that: (1) all catches off Japan are assumed to be Western stock animals; and (2) the abundance estimates off Sakhalin Island are assumed to relate only to the Western stock. Thus the Workshop agreed to change the status of this hypothesis to high priority (IWC, 2017). However, upon reconsideration, the Workshop noted that, while the possibility that gray whales use multiple wintering grounds could not be ruled out, hypotheses 6b would be considered as a sensitivity test (IWC, 2019).

[1]In some previous descriptions of the hypotheses, EBS whales were described as also using both wintering grounds (M and VSC), showing no fidelity to either. However, in the model structure only WBS whales use both wintering grounds, and so the description has been amended here.

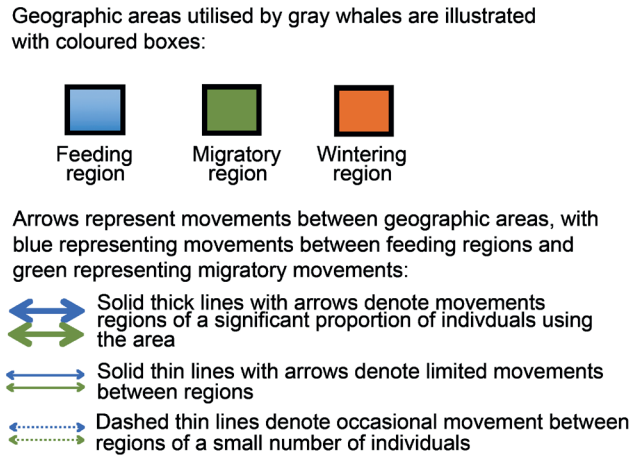

Fig. 1. Key to interpreting the stock structure schematics.

Figure 2 (a) Hypothesis 3a/4a

3a: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating. A single breeding stock (EBS) exists. The EBS includes three feeding groups: NFG, PCFG, WFG. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG. Although two breeding stocks (WBS and EBS) may once have existed, the WBS is assumed to have been extirpated.

4a: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating. Two breeding stocks exist and overwinter in M. One breeding stock includes NFG and PCFG, and the second breeding stock includes WFG whales. Separation between breeding stocks is maintained by WFG whales mating largely with each other while migrating to M. SKNK is used by some whales that belong to the breeding stock comprised of WFG whales and some whales that belong to the NFG. Although a third breeding stock (the WBS) may once have existed, the WBS is assumed to have been extirpated.

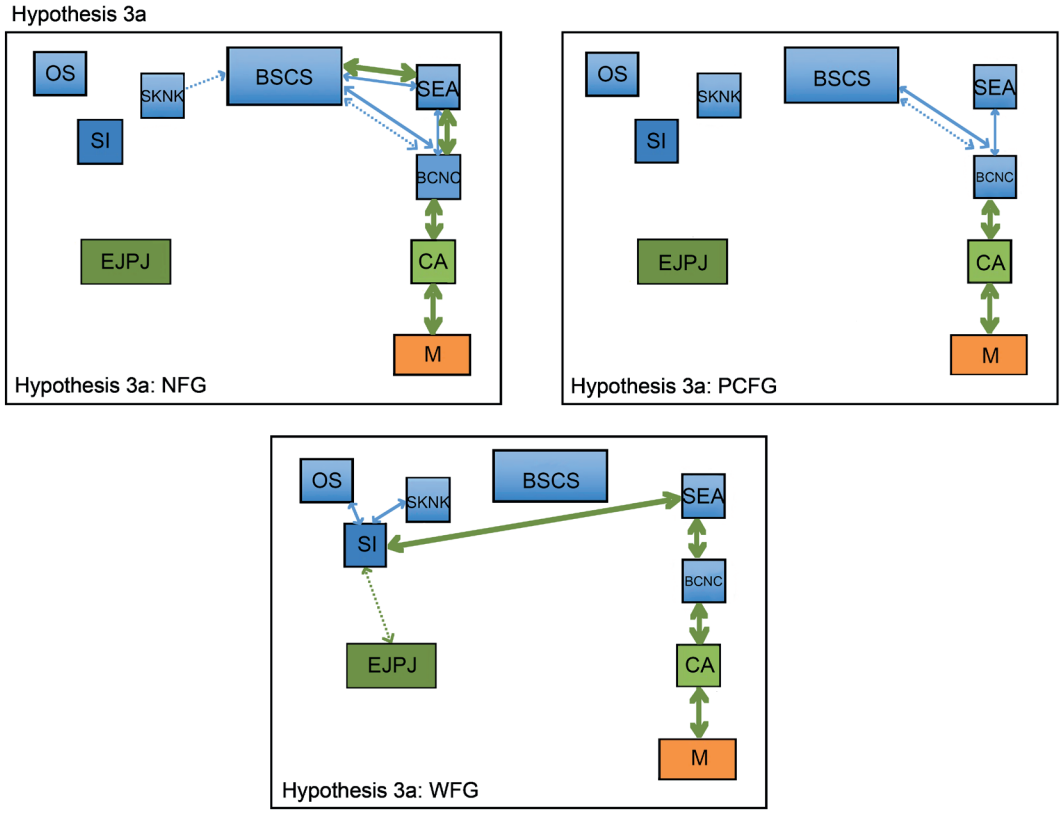

Figure 2 (b) Hypothesis 5a

Hypothesis 5a. Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, random mating. Two breeding stocks exist: EBS and WBS. The EBS includes three feeding groups: PCFG, North, and the WFG that feeds off SI. The WBS whales feed in SI, OS, and SKNK and then migrate to VSC to overwinter. SKNK is used by the WFG, the NFG, and the feeding whales that are part of the WBS.

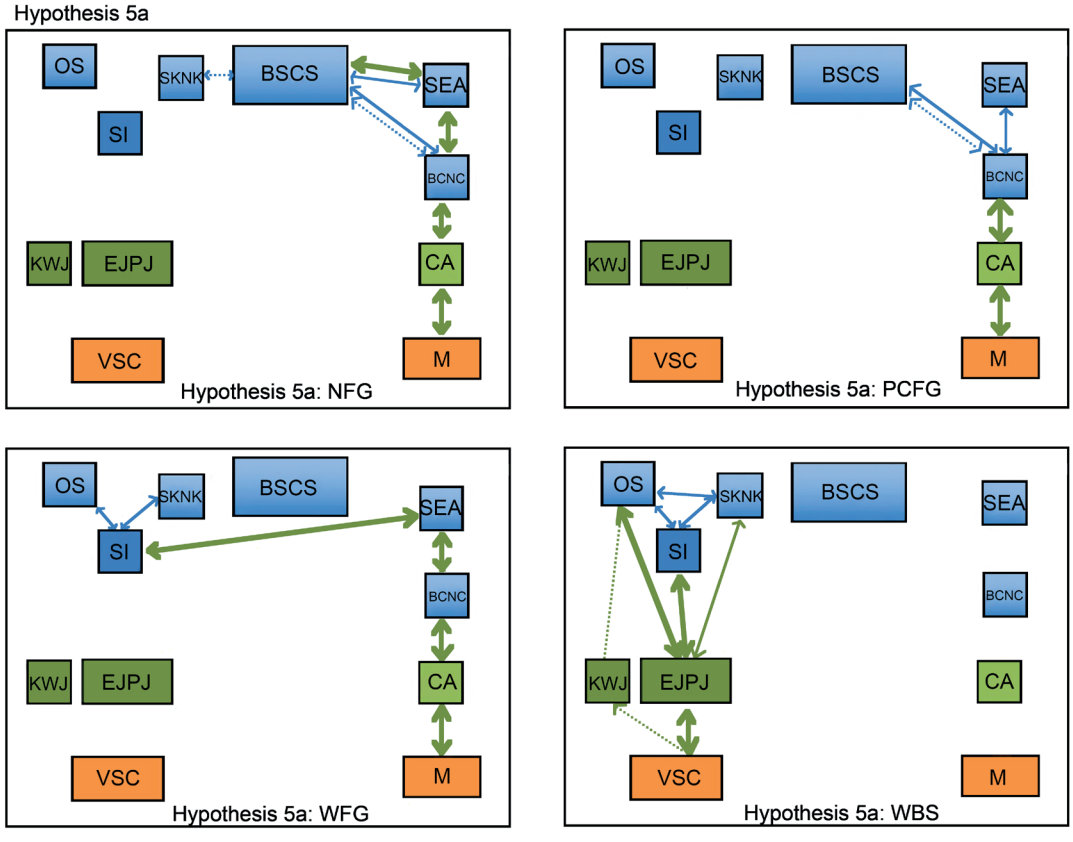

Fig. 2. Schematics of the stock structure hypotheses currently considered to have high plausibility.
Note that Hypothesis 4a is functionally equivalent to Hypotheses 3a, and thus the schematic shown in (a) represents both hypotheses.

Figure 3 (a) Hypothesis 3b/4b:
Hypothesis 3b: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating. An EBS exists that includes three feeding groups (NFG, PCFG, and WFG). In addition, a WBS exists that overwinters in VSC and feeds in the OS (but not SI) and SKNK. SKNK is used by both the WFG whales and the whales of the WBS.

Hypothesis 4b: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating. An EBS exists that includes two feeding groups (NFG and PCFG). A WBS exists that overwinters in VSC and feeds in the OS (but not SI) and SKNK. A third breeding stock includes WFG whales that mate largely with each other while migrating to M. SKNK is used by both the WFG whales and the whales of the WBS.

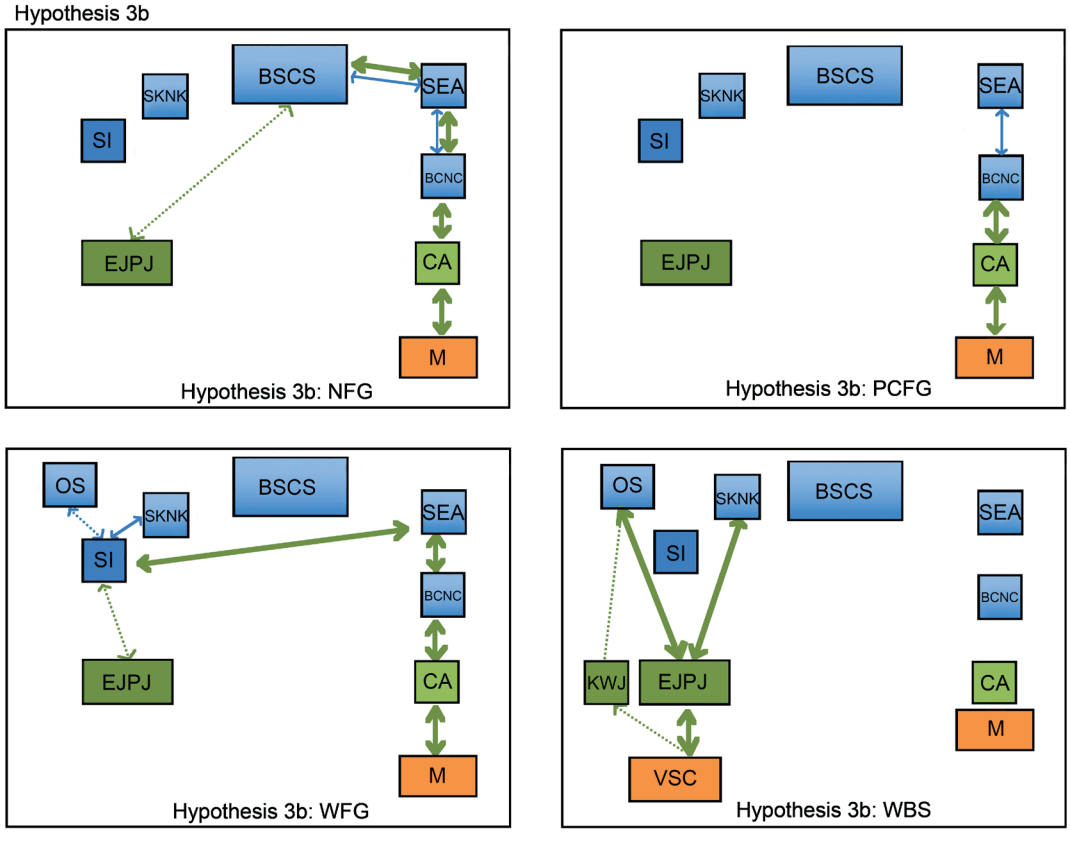

Figure 3(b) Hypothesis 3c/4c:
Hypothesis 3c: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating. A single breeding stock (EBS) exists. The EBS includes three feeding groups: NFG, PCFG, WFG. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG. Although two breeding stocks (WBS and EBS) may once have existed, the WBS is assumed to have been extirpated. WFG whales migrating from SI to M occasionally travel through BSCS.

Hypothesis 4c: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating. An EBS exists that includes two feeding groups: NFG and PCFG. A second breeding stock exist that is comprised of WFG whales that overwinter in M. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG. Although a third breeding stock (WBS) may once have existed, the WBS is assumed to have been extirpated. WFG whales migrating from SI to M occasionally travel through BSCS.

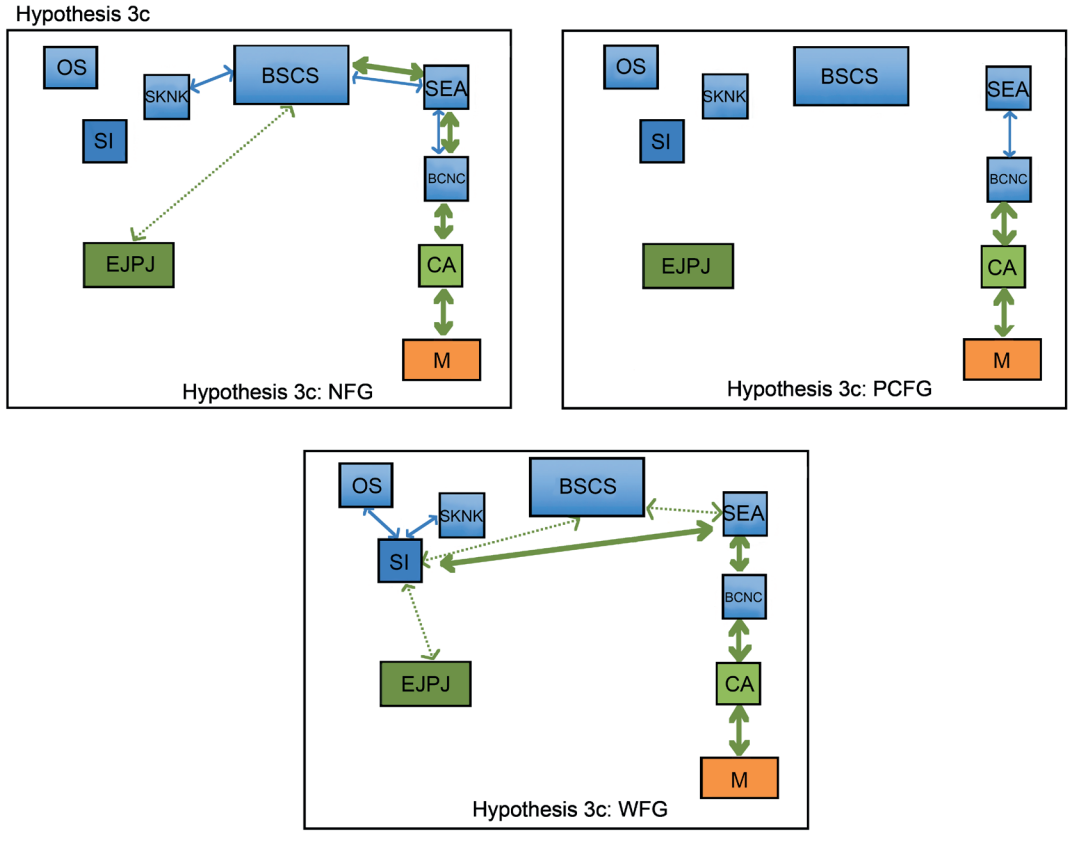

Figure 3 (c) Hypothesis 3e/4e

Hypothesis 3e: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating. A single breeding stock (EBS) exists. The EBS includes three feeding groups: NFG, PCFG, WFG. A WBS exists that feeds in the OS (but not SI), EJPJ, and KWJ and overwinters in VSC. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG, but not regularly by whales that are part of the WBS.

Hypothesis 4e: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating. The EBS includes two feeding groups: NFG and PCFG. A WBS exists that feeds in the OS (but not SI), EJPJ, and KWJ and overwinters in VSC. A third breeding stock comprised of the WFG whales that overwinter in M exists. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG but not regularly by whales that are part of the WBS.

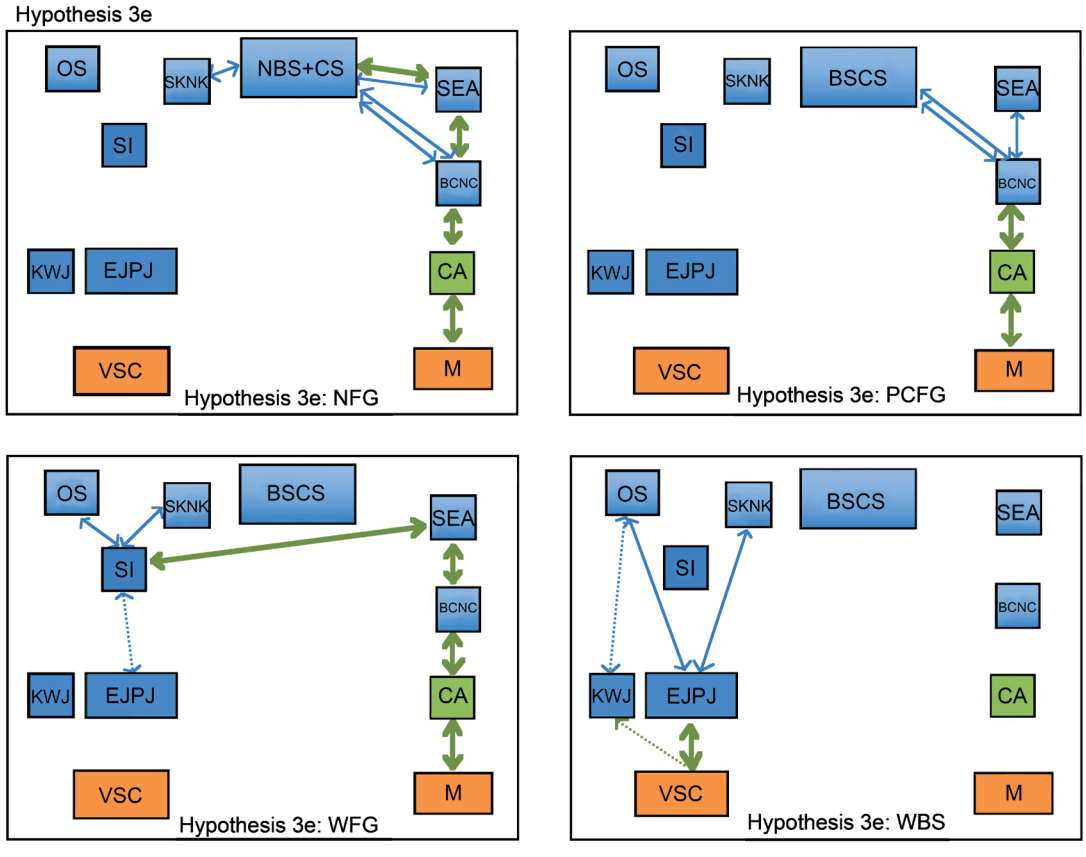

Figure 3 (d) Hypothesis 6b

Hypothesis 6b. Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds without fidelity, random mating. Two breeding stocks (WBS and EBS) and three feeding groups (WFG, NFG, and PCFG) exist. SKNK is used by both the WFG and NFG. The WBS stock includes WFG whales, while the EBS stock includes NFG and PCFG whales. WBS whales use both wintering grounds (M and VSC). WBS individuals do not show fidelity for a particular wintering ground but do breed largely with each other during migration. EBS whales overwinter in M.

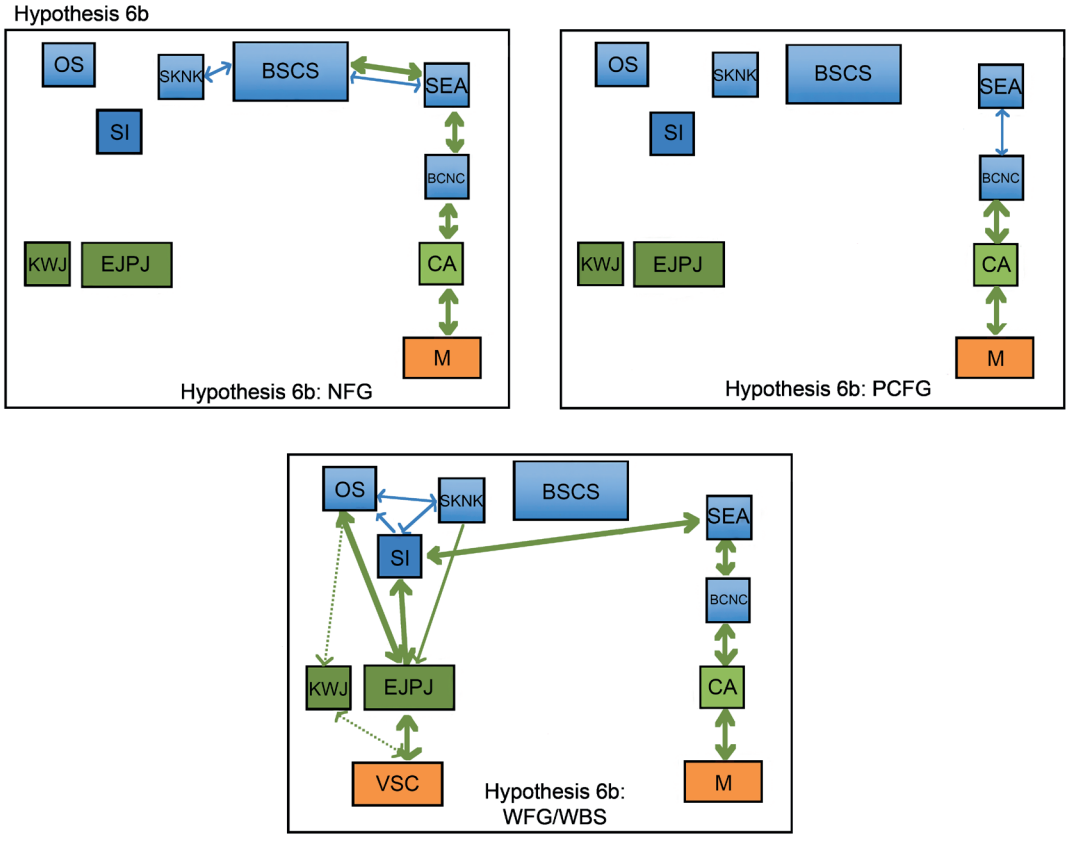

Fig. 3. Schematics of the stock structure hypotheses currently considered to have medium plausibility. Hypotheses that are functionally the same are represented by a single diagram with descriptions of both.

Table 4 [copied from Table 2, IWC (2019)].

The mixing matrices for stock structure hypotheses 3a, 3b, 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.

	Sub-area													
Breeding stock/ Feeding Aggregation	VSC	KWJ	EJPJ	OS	SI	SKNK	BSCA	SEA (J-N)	SEA (D-M)	BCNC (J-N)	BCNC (D-M)	CA (J-N)	CA (D-M)	M
a. Hypothesis 3a (no extant WBS)														
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	-	-	$\gamma 6$	-	$\gamma 3$	-	$\gamma 6$	1
North	-	-	$\gamma 1$	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	1 [A]	$\gamma 8$ [B]	$\gamma 7$	$\gamma 2$	$\gamma 4$	$\gamma 5$	$\gamma 7$	1
b. Hypothesis 3b (extant WBS)														
Western	1	1	$\gamma 1$	1	-	-	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	-	1	1	1	-	-	$\gamma 6$	-	$\gamma 3$	-	$\gamma 6$	1
North	-	-	1	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	$\gamma 7$	$\gamma 2$	$\gamma 4$	$\gamma 5$	$\gamma 7$	1
c. Hypothesis 3c (extant WBS, WFG in BSCS)														
Western	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	1	-	$\gamma 6$	-	$\gamma 3$	-	$\gamma 6$	1
North	-	-	$\gamma 1$	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	$\gamma 7$	$\gamma 2$	$\gamma 4$	$\gamma 5$	$\gamma 7$	1
d. Hypothesis 3e (extant WBS; WFG in EJPJ)														
Western	1	1	$\gamma 1$	1	-	1	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	-	-	$\gamma 6$	-	$\gamma 3$	-	$\gamma 6$	1
North	-	-	-	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	$\gamma 7$	$\gamma 2$	$\gamma 4$	$\gamma 5$	$\gamma 7$	1
e. Hypothesis 5a (WBS in SI)														
Western	1	1	$\gamma 1$	1	1	1	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	-	-	$\gamma 6$	-	$\gamma 3$	-	$\gamma 6$	1
North	-	-	-	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	1 [C]	$\gamma 8$ [D]	$\gamma 7$	$\gamma 2$	$\gamma 4$	$\gamma 5$	$\gamma 7$	1
f. Hypothesis 6b (no WFG)														
Western	1	1	1	1	1	1	-	-	$\gamma 6$	-	$\gamma 3$	-	$\gamma 6$	1
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
North	-	-	-	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	$\gamma 7$	$\gamma 2$	$\gamma 4$	$\gamma 5$	$\gamma 7$	1

[A] Sensitivity test (12) only.
[B] Sensitivity test (9) only.
[C] Sensitivity test (12) only.
[D] Sensitivity test (9) only.

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