Report of the Scientific Committee

Virtual Meetings, 27 April-14 May 2021

Annex G: Summary of Gray Whale Stock Structure Hypotheses

This report is presented as it was at SC/68C.
There may be further editorial changes (e.g. updated references, tables, figures) made before publication.

International Whaling Commission
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Annex G

Summary of Gray Whale Stock Structure Hypotheses

During the Rangewide Workshops on the Population Structure and Status of Gray Whales in the North Pacific that were held between 2014-2018 (IWC, 2018), a series of hypotheses were put forward to explain the stock structure of gray whales in the North Pacific. These hypotheses were evaluated in light of the available evidence, resulting in two hypotheses (3a and 5a) being identified as a high priority for inclusion in the modelling framework used to evaluate the status of North Pacific gray whales. Four additional variants (3b, 3c, 3e, and 6b) were ranked as medium plausibility and were included as sensitivity tests. After receiving new information that pertained to stock structure, the Committee re-evaluated the plausibility of hypothesis 4a and its variants and determined that hypothesis 4a should be assigned high plausibility and its variants as medium plausibility (Annex F, IWC 2021). Additional evaluation of these hypotheses continued at SC68C (see 10.2.3), leading to the plausibility of hypothesis 7a being elevated to high priority while hypotheses 3a and 5a were considered medium plausibility. Of note, however, hypotheses 3a and 4a and hypotheses 5a and 7a are functionally equivalent and thus no new model runs are required to evaluate them.

The medium and high priority hypotheses, and their updated status, are described below.

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 #9763}.
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, 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
Vietnam-South China Sea	VSC
Korea and western side of the Sea of Japan	KWJ
Eastern side of the Sea of Japan and the Pacific coast of Japan	EJPJ
Northeastern Sakhalin Island	SI
Southern Kamchatka and Northern Kuril Islands*	SKNK
Areas of the Okhotsk Sea not otherwise specified	OS
Northern Bering and Chukchi Sea	BSCS
Southeast Alaska	SEA
British Columbia to Northern California	BCNC
California	CA
Mexico	M
Latent subarea	Calif-3
Latent subarea	BC-BCA-3

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

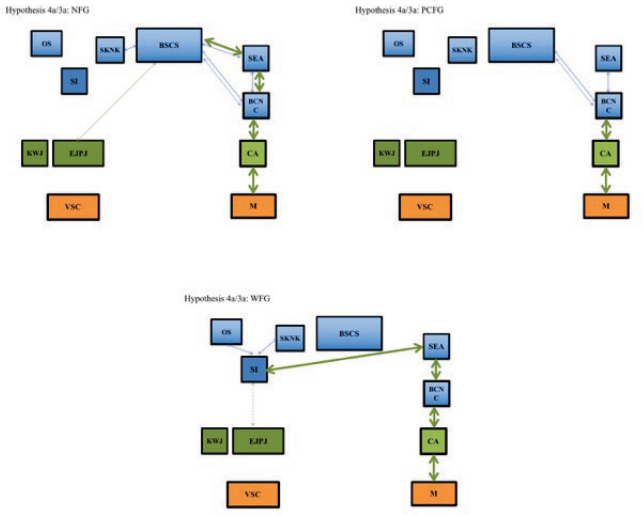
Table 3 [updated from Table 3, Annex F, IWC(2021)]
A summary of the stock structure hypotheses and their status after consideration at SC68C.

Description	Plausibility	Comment
(3) Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating within the EBS		
(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.	Medium	Originally ranked as high, but upon consideration of evidence indicating that Sakhalin whales that travel to Mexico do not randomly mate with NFG and PCFG whales, the hypothesis was ranked as medium, while noting that it is functionally the same as hypothesis 4a (IWC 2021)
(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, 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 (EBS) 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, 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 (IWC 2021).
(b) Three breeding stocks exist. As in 4a, the EBS includes the NFG and PCFG whales; however, unlike 4a here the NFG whales do not feed off SKNK. A second breeding stock includes WFG whales that mate largely with each other while migrating to M. 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	Initially regarded as low priority because it is represented in the same way as other hypotheses in modeling (IWC, 2015). After re-evaluation, 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 (IWC 2020). Note that the corollary hypothesis (3b) was originally considered low priority because there were few or no data to assess plausibility (IWC, 2015), but availability of abundance estimates for combined SKNK + SI (Cooke, 2017) made feasible to assess
(c) Same as 4a except that whales that are part of the breeding stock comprised of WFG whales that largely breed with each other while on migration to M exists occasionally travel through BSCS.	Medium	Sensitivity test. 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 (IWC 2020).
(e) Same as 4a 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 4b, with the exception that SKNK region is not used regularly by whales part of the WBS.	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 (IWC 2020). Note that the corollary hypothesis (3e) was 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).
(5) Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, random mating within the EBS		
(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.	Medium	Originally ranked as high, but upon consideration of evidence indicating that Sakhalin whales that travel to Mexico do not randomly mate with NFG and PCFG whales, the hypothesis was ranked as medium, while noting that it is functionally the same as hypothesis 7a (See 10.2.3)
(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).
(7) Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, non-random mating		
(a) Same as 5a except that three breeding stocks exist: EBS and WBS and an unnamed stock of WFG whales that largely breed with each other while on migration to M exists. The EBS includes two feeding groups: PCFG and North. The WBS whales feed in SI, OS, and SKNK and then migrate to VSC to overwinter. SKNK is used by the WFG (that are part of the unnamed breeding stock migrating to M), the NFG, and the feeding whales that are part of the WBS.	High	Originally ranked as low priority but upon consideration of evidence indicating that the Sakhalin whales that travel to Mexico do not randomly mate with NFG and PCFG whales, the hypothesis was ranked as high (see 10.2.3).

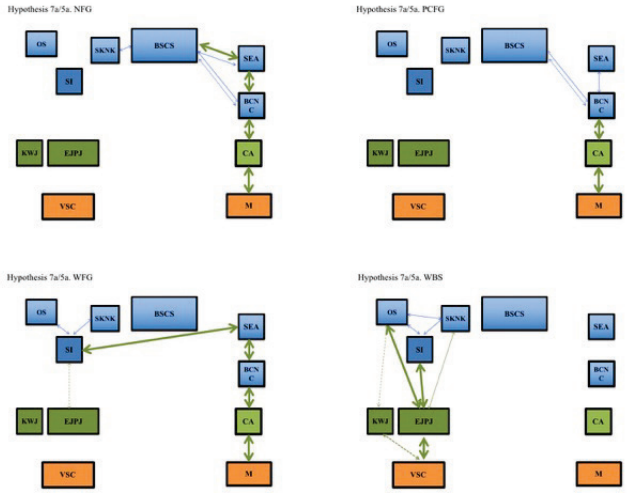
[1]In some previous descriptions of the hypotheses, EBS whales were described as also using both wintering grounds (M and VSC), showing no fidelity to either. However, in the model structure only WBS whales use both wintering grounds, and so the description has been amended here.

High priority hypotheses:

Hypothesis 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.



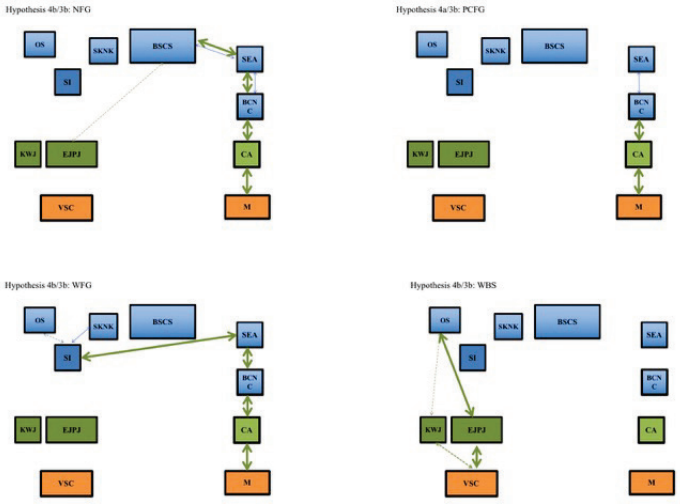
Hypothesis 7a. Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, non-random mating. Same as 5a except that three breeding stocks exist: EBS and WBS and an unnamed stock of WFG whales that largely breed with each other while on migration to M exists. The EBS includes two feeding groups: PCFG and North. The WBS whales feed in SI, OS, and SKNK and then migrate to VSC to overwinter. SKNK is used by the WFG (that are part of the unnamed breeding stock migrating to M), the NFG, and the feeding whales that are part of the WBS.



Medium priority hypotheses:

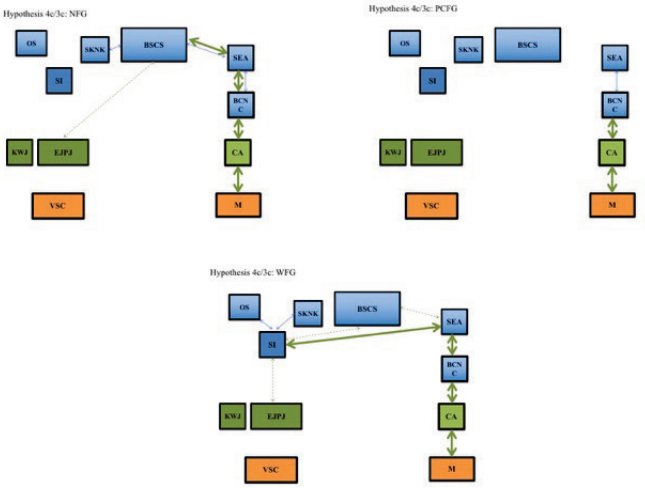
Hypothesis 3a: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating within. The EBS. A single breeding stock (EBS) exists. The EBS includes three feeding groups: NFG, PCFG, WFG. SKNK is used by some whales that belong to the WFG and some whales that belong to the NFG. Although two breeding stocks (WBS and EBS) may once have existed, the WBS is assumed to have been extirpated. For diagram see Hypothesis 4a above.

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.



Hypothesis 3b: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating within the EBS. 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. For diagram see Hypothesis 4b above.

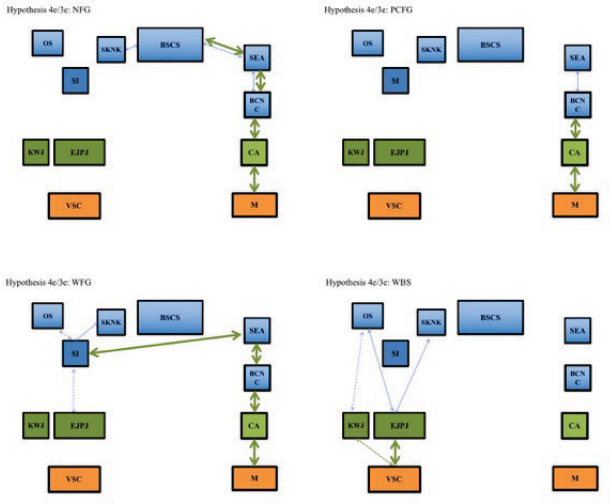
Hypothesis 4c: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating. An EBS exists that includes two feeding groups: NFG and PCFG. A second breeding stock exist that is comprised of WFG whales that overwinter in M. SKNK is used by some whales 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.



Hypothesis 3c: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating within the EBS. 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.

For diagram see Hypothesis 4c above.

Hypothesis 4e: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, non-random mating within the EBS. 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.



Hypothesis 3e: Maternal feeding ground fidelity, one migratory route/wintering region used by Sakhalin whales, random mating within the EBS. 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.

For diagram see Hypothesis 4e above.

Hypothesis 5a: Maternal feeding ground fidelity, two migratory routes/wintering grounds used by Sakhalin whales, random mating within the EBS. 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.

For diagram see hypothesis 7a above.

Hypothesis 6b: Maternal feeding ground fidelity, Sakhalin whales use two migratory routes/wintering grounds without fidelity. 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.

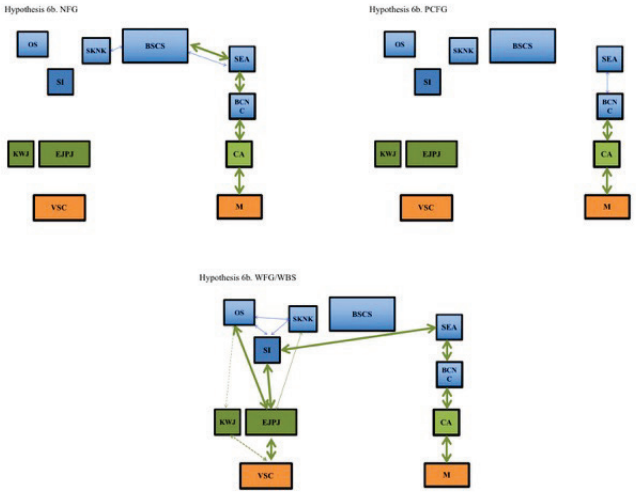


Table 4 [copied from Table 2, IWC (2019)]

The mixing matrices for stock structure hypotheses 4a/3a, 4b/3b, 4c/3c, 4e/3e, 7a/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	BSCS	SEA (J-N)	SEA (D-M)	BCNC (J-N)	BCNC (D-M)	CA (J-N)	CA (D-M)	M
a. Hypothesis 4a/3a (no extant WBS)														
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	-	-	γ6	-	γ3	-	γ6	1
North	-	-	γ1	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	1 [A]	γ8[B]	γ7	γ2	γ4	γ5	γ7	1
b. Hypothesis 4b/3b (extant WBS)														
Western	1	1	γ1	1	-	1	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	-	1	1	1	-	-	γ6	-	γ3	-	γ6	1
North	-	-	1	-	-	-	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	γ7	γ2	γ4	γ5	γ7	1
c. Hypothesis 4c/3c (extant WBS, WFG in BSCS)														
Western	1	1	-	-	-	-	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	1	-	γ6	-	γ3	-	γ6	1
North	-	-	γ1	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	γ7	γ2	γ4	γ5	γ7	1
d. Hypothesis 4e/3e (extant WBS; WFG in EJPJ)														
Western	1	1	γ1	1	-	1	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	-	-	γ6	-	γ3	-	γ6	1
North	-	-	-	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	γ7	γ2	γ4	γ5	γ7	1
e. Hypothesis 7a/5a (WBS in SI)														
Western	1	1	γ1	1	1	1	-	-	-	-	-	-	-	-
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WFG	-	-	1	1	1	1	-	-	γ6	-	γ3	-	γ6	1
North	-	-	-	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	1 [C]	γ8[D]	γ7	γ2	γ4	γ5	γ7	1
f. Hypothesis 6b (no WFG)														
Western	1	1	1	1	1	1	-	-	γ6	-	γ3	-	γ6	1
Eastern	-	-	-	-	-	-	-	-	-	-	-	-	-	-
North	-	-	-	-	-	1	1	1	1	1	1	1	1	1
PCFG	-	-	-	-	-	-	-	1	γ7	γ2	γ4	γ5	γ7	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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