Appendix 6

The Specifications for the *Implementation Simulation Trials* for western North Pacific Bryde's whales

A. Basic concepts and stock-structure

The trials outlined below consider the implications of alternative variants of the RMP for Bryde's whales in sub-areas 1 and 2 of the western North Pacific (Fig. 1). Sub-area 1 is further sub-divided into sub-areas 1W and 1E at 165^{0}E for the bulk of the trials although sensitivity is explored to alternative placements of the boundary in some of the trials. The trials consider up to two *stocks* of Bryde's whales in the western North Pacific, one of which (Stock 1) could consist of two *sub-stocks* that mix across sub-area 1 and perhaps also sub-area 2. Sub-stocks are modelled as stocks (i.e. there is no permanent transfer of animals among sub-stocks) for ease of implementation, because it should provide a more stringent test of the RMP variants, and because there are no data to estimate rates of dispersal among putative sub-stocks nor any way to estimate dispersal rates.

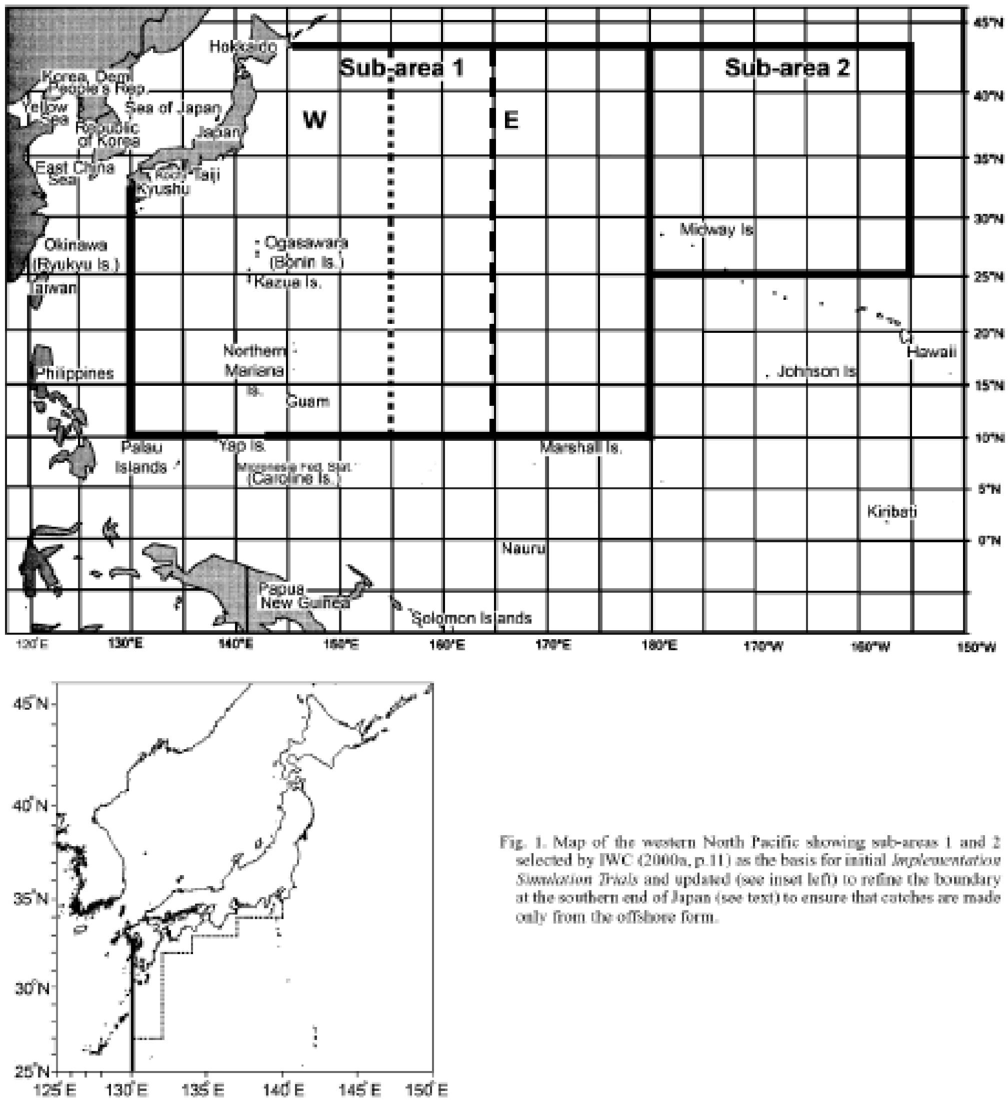

Fig. 1. Map of the western North Pacific showing sub-areas 1 and 2 selected by IWC (2000a, p.11) as the basis for initial *Implementation Simulation Trials* and updated (see inset left) to refine the boundary at the southern end of Japan (see text) to ensure that catches are made only from the offshore form.

Fig. 1. Map of the western North Pacific showing the sub-areas defined for the western North Pacific Bryde's whales. Note: the boundary between the 1W and 1E subareas is now set at 165°E.

There are four general hypotheses regarding stock structure:

(1) There is only one stock of Bryde's whales in sub-areas 1 and 2.
(2) There are two stocks of Bryde's whales in sub-areas 1 and 2. One stock is found in sub-area 1 and the other is found in sub-area 2.
(3) There are two stocks of Bryde's whales in sub-areas 1 and 2. One stock is found in sub-areas 1 and 2, and the other is found in sub-area 2 only.
(4) There are two stocks of Bryde's whales in sub-areas 1 and 2. One stock is found in sub-area 1 and the other is found in sub-area 2. Stock 1 consists of two sub-stocks that mix in sub-areas 1W and 1E.

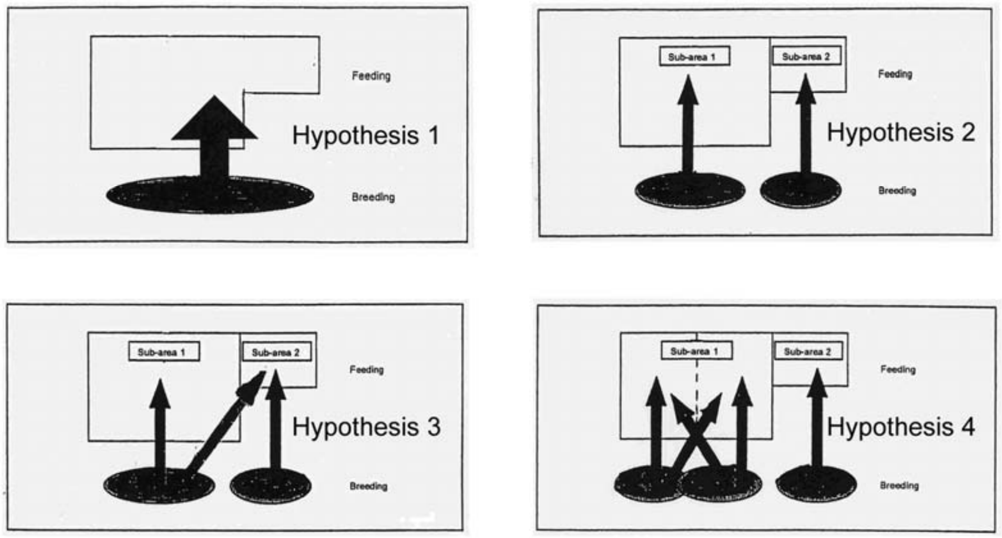

Fig. 2. Stock structure hypotheses selected by the Workshop on the *pre-implementation assessment* of the western North Pacific Bryde's whales.

B. Basic dynamics

The dynamics of the animals in stock/sub-stock *j* are governed by the equations:

$$N^{g,j}_{t+1,a} = \begin{cases} 0.5\, b^j_{t+1} & \text{if } a = 0 \\ (N^{g,j}_{t,a-1} - C^{g,j}_{t,a-1})e^{-M} & \text{if } 1 \le a < x \\ (N^{g,j}_{t,x} - C^{g,j}_{t,x})e^{-M} + (N^{g,j}_{t,x-1} - C^{g,j}_{t,x-1})e^{-M} & \text{if } a = x \end{cases} \tag{B.1}$$

where $N^{g,j}_{t,a}$ is the number of animals of gender *g* and age *a* in stock/sub-stock *j* at the start of year *t*;

$C^{g,j}_{t,a}$ is the catch (in number) of animals of gender *g* and age *a* in stock/sub-stock *j* during year *t* (whaling is assumed to take place in a pulse at the start of each year)

b^j_t is the number of calves born to females from stock/sub-stock *j* at the start of year *t*;

M is the instantaneous rate of natural mortality; and

x is the maximum age (treated as a plus-group).

C. Births

Density-dependence is assumed to act on the female component of the 'mature' population. The convention of referring to the mature population is used here, although this actually refers to animals that have reached the age of first parturition.

$$b^j_t = B^j N^{\mathrm{f},j}_t \{1 + A^j(1 - (N^{\mathrm{f},j}_t / K^{\mathrm{f},j})^{z^j})\} \tag{C.1}$$

where B^j is the average number of births (of both sexes) per year for a mature female in stock/sub-stock *j* in the pristine population;

A^j is the resilience parameter for stock/sub-stock *j*;

z^j is the degree of compensation for stock/sub-stock *j*;

$N^{\mathrm{f},j}_t$ is the number of 'mature' females in stock/sub-stock *j* at the start of year *t*:

$$N^{\mathrm{f},j}_t = \sum_{a=a_m}^{x} N^{\mathrm{f},j}_{t,a} \tag{C.2}$$

a_m is the age-at-first-parturition; and

$K^{\mathrm{f},j}$ is the number of mature females in stock/sub-stock *j* in the pristine (pre-exploitation written as t=-∞) population:

$$K^{\mathrm{f},j} = \sum_{a=a_m}^{x} N^{\mathrm{f},j}_{-\infty,a} \tag{C.3}$$

The values of the parameters A^j and z^j for each stock/sub-stock are calculated from the values for $MSYL^j$ and $MSYR^j$ (Punt, 1999). Their calculation assumes harvesting equal proportions of males and females.

D. Catches

It is assumed that whales are homogeneously distributed across a sub-area. The catch limit for a sub-area is therefore allocated to stocks/sub-stocks by sex and age relative to their true density within that sub-area and a mixing matrix *V* which depends on year (but is independent of sex), i.e.:

$$C^{g,j}_{t,a} = \sum_k F^{g,k}_t V^{j,k}_{t,a} S^k_{t,a} N^{g,j}_{t,a} \tag{D.1}$$

$$F^{g,k}_t = \frac{C^{g,k}_t}{\sum_{j'} V^{j',k}_t \sum_{a'} S^k_{t,a'} N^{g,j'}_{t,a'}} \tag{D.2}$$

where	$F^{g,k}_t$	is the exploitation rate in sub-area *k* on recruited animals of sex *g* during year *t*;
	$S^k_{t,a}$	is the selectivity on animals of age *a* in sub-area *k* during year *t*;
	$C^{g,k}_t$	is the catch of animals of sex *g* in sub-area *k* during year *t*; and
	$V^{j,k}_{t,a}$	is the fraction of animals of age *a* in stock/sub-stock *j* that is in sub-area *k* during year *t*.

Most trials assume that the mixing matrix does not depend on age. The exceptions are trials Br11 and Br12 in which there is age-dependency in the distribution across sub-area 1. In these trials the values for the entries in the mixing matrix are set using the following equation:

$$\begin{aligned} V^{j,1W}_{t,a} &= V^{j,1W}_{t,0}(1-\lambda a) \\ V^{j,1E}_{t,a} &= (1-V^{j,1W}_{t,a}) \end{aligned} \tag{D.3}$$

where λ is a parameter which determines the extent to which the mixing matrix depends on age. The value of λ is determined during conditioning (see section G(d)).

The catches by sub-area and year are either set to the historical (pre-2005) values (Table 2); or, in the future, are determined using the RMP. The sex ratio for future catches is assumed to be 50:50.

E. Mixing

The entries in the mixing matrix *V* are selected to model the distribution of each stock/sub-stock at the time when the catch is removed. Mixing can be deterministic or stochastic. If mixing is stochastic, the mixing matrix is selected at random from two possibilities. Table 1 lists the mixing matrices for each of the stock structure hypotheses. Mixing is stochastic for the trials in which Stock 1 or Sub-stock 1E is found in sub-area 2 (Br6 and 7, hypothesis 3). A random number, *u*, is selected from U[0,1] for each year. If $u \leq 0.5$, Stock 1/ Sub-stock 1E mixes into sub-area 2 otherwise no mixing takes place. A similar scheme is used to model stochastic mixing of Sub-stocks 1W and 1E in sub-areas 1W and 1E for trials Br13 and Br14, with the 1W and 1E substocks assumed to move in phase in order to minimise or maximise the overlap (i.e. a single random number is selected and applied to both substocks).

In most trials, the boundary between sub-areas 1W and 1E used when modelling the true population dynamics is the same as that used when applying the RMP (and is at 165°E). However, for some of trials based on stock structure hypothesis 4, a different boundary is used.

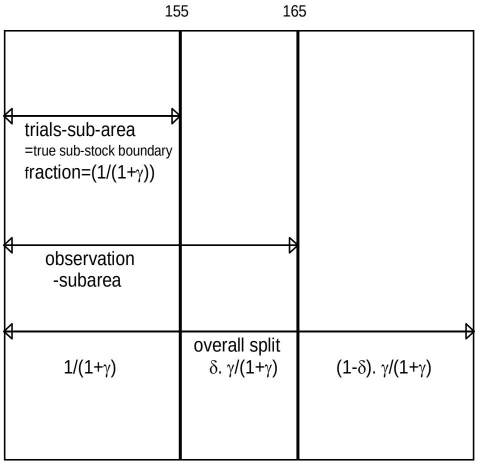

Fig. 3. Illustration of how trials sub-areas and observation sub-areas operate for trials in which trials sub-areas and observation sub-areas differ.

Consider the case in which the true boundary between the sub-stocks on which the trials are based and to which the mark-recapture data pertain (trials-sub-areas) is at 155°E and that between the sub-areas for which catches are reported and survey abundance estimates are available (observation-sub-areas) is 165°E (Fig. 3). The mixing matrix for either of the sub-stocks can conveniently be expressed as the vector (1, γ) where a fraction of γ/(1+γ) of the animals from the stock are found to the east of 155°E and 1/(1+γ) are found west of 155°E. Now assume that a fraction δ of the animals in the sub-area east of 155°E are located between 155°E and 165°E. The split of the stock among the three sectors: 140°E-155°E; 155°E-165°E;165°E-180° is therefore 1/(1+γ), δγ/(1+γ), and (1-δ)γ/(1+γ).

The value of δ is set assuming that a stock (or sub-stock) is uniformly distributed across the area in which it is found. Thus, δ=2/5 when the stock boundary is at 155°E and the RMP boundary is at 165°E. (Note: the boundary used by the RMP is always the same as the true boundary in trials when mixing is age dependent.)

Note that the tagging data are assigned to stocks/ sub-stocks (and reported) according the trials-sub-areas and not the observation sub-areas.

F. Generation of Data

The actual estimates of absolute abundance (and their associated CVs) for 1995 (Table 3) are provided to the RMP. These abundance estimates exclude the areas identified in table 3 of IWC (2000). The future surveys are assumed to cover each of sub-areas 1W, 1E and 2 in their entirety in a single survey. This is a slight simplification of reality; the entire area will actually be covered in four years (see Table 4 for the proposed survey plan), but the westernmost part of sub-area 1W contains very few Bryde's whales so the two surveys in sub-area 1W are treated as one for the purposes of trials. The trials assume that it takes two years for the results of a sighting survey to become available to be used by the management procedure, i.e. a survey conducted in 2006 could first be used for setting the catch limit in 2008.

The future estimates of abundance for a survey area (a sub-area for these trials) (say survey area E) are generated using the formula:

$$\hat{P} = P\,Y\,w/\mu = P^*\,\beta^2\,Y\,w \qquad \text{(F.1)}$$

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

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 *E*:

$$P = P_t^E = \sum_{k\in F}\sum_j V_t^{j,k}\sum_g\sum_{a\geq 1} N_{t,a}^{g,j} \qquad \text{(F.2)}$$

P^* is the reference population level, and is equal to the expected total (1+) population size in the survey area prior to the commencement of exploitation in the area being surveyed (where the expectation is taken with respect to inter-annual variation in the mixing matrix); and

F is the set of sub-areas making up survey area *E*.

Note that under the approximation $CV^2(ab) = CV^2(a) + CV^2(b)$, $E(\hat{P}) = P$ and $CV^2(\hat{P}) = \alpha^2 + \beta^2 P^*/P$. For consistency with the first stage screening trials for a single stock (IWC, 1991, p.109; IWC 1994, p.85), the ratio $\alpha^2 : \beta^2 = 0.12 : 0.025$, so that:

$$CV^2(\hat{P}) = \tau(0.12 + 0.025P^*/P) \qquad \text{(F.3)}$$

An estimate of the CV, *X*, is generated for each sightings estimate:

$$X = \sigma\sqrt{(CHISQ/n)} \qquad \text{(F.4)}$$

where $\sigma^2 = \ell\text{n}(1 + CV_{est}^2)$ and CHISQ is a random number from a Chi-square distribution with *n* degrees of freedom (where *n* is …) and $CV_{est}^2 = \theta^2(a^2 + b^2/w\beta^2)$ where a^2 and b^2 are constants and equal 0.02 and 0.012 respectively. Note that under the approximation $E(1/w) = 1/E(w) = 1/[(P/P^*)/\beta^2] = \beta^2 P^*/P$, this gives:

$$CV_{est}^2 = \theta^2(a^2 + b^2 P^*/P) \qquad \text{(F.5)}$$

The equation used to compute θ^2 for a given sub-area is:

$$\theta^2 = CV_{\tilde{P}}^2 /(0.02 + 0.012P^*/\tilde{P}) \qquad \text{(F.6)}$$

where $CV_{\tilde{P}}$ is the observed CV (excluding additional variance) corresponding to some model population size $\tilde{P}$. The extent of additional variance, σ_p^2, is defined as the additional variance at $P = \tilde{P}$, i.e.:

$$CV^2(\tilde{P}) = CV_{est}^2(\tilde{P}) + \sigma_p^2 \qquad \text{(F.7)}$$

The value for τ (and hence those for α^2 and β^2) can be computed from values for θ^2, σ_p^2, and Equations (F.5), (F.6), and (F.7) as follows:

$$\tau = \frac{CV_{\tilde{P}}^2 + \sigma_p^2}{0.12 + 0.025P^*/\tilde{P}} \qquad \text{(F.8)}$$

Adjunct 1 lists the values for $CV_{\tilde{P}}$ and σ_p^2 by sub-area.

G. Parameters and conditioning

The values for the biological and technological parameters are listed in Table 5. In relation to selectivity, a 35ft (10.7m) legal minimum size limit applies to coastal whaling and a 40ft (12m) limit applies to pelagic operations. These limits correspond to ages of five and nine years respectively (Ohsumi, 1977). These limits can be implemented by making selectivity depend on sub-area. Historically, pelagic whaling occurred in sub-areas 1E and 2, and coastal whaling in sub-area 1W. Therefore, selectivity is assumed to be knife-edged at age five for sub-area 1W, while selectivity for sub-areas 1E and 2 is assumed to be knife-edged at age nine. All future catches are assumed to be based on pelagic whaling with knife-edged selectivity at age five**.**

The 'free' parameters of the above model are the initial (pre-exploitation) sizes of each of the sub-stocks/stocks and the values that determine the mixing matrices. The conditioning process involves first generating 100 sets of 'target' data, detailed in steps (a) to (d) below, and then fitting the population model to each (in the spirit of a bootstrap). Note that each replicate involves different realizations for the random variables that determine the mixing matrices.

(a) The 'target' values for the historical abundance by sub-area are generated using the formula:

$$P_t^k = O_t^k \exp[\mu_t^k - (\sigma_t^k)^2/2]\,;\ \mu_t^k \sim N[0;(\sigma_t^k)^2] \qquad \text{(G.1)}$$

where P_t^k is the abundance for sub-area *k* in year *t*;

O_t^k is the actual survey estimate for sub-area *k* in year *t* (Table 3); and

σ_t^k is the CV is O_t^k .

(b) A 'target' for the numbers of animals tagged in sub-areas 1 and 2 during 1972–85 and recaptured by the Japanese fleets is generated by selecting records with replacement from the tag-recapture data (see tables 7 and 8). The objective function used to include the tagging data when conditioning is given in Adjunct 3. The tag recapture data are assumed to be negative binomially (rather than Poisson) distributed to account for possible non-randomness in the tagging / recapture process.

(c) A target for the ratio of the number of 1+ animals from Stock 2 in sub-area 2 to those from Stock 1 in sub-area 2 (for trials that involve mixing of Stocks 1 and 2 in sub-area 2 only i.e. hypothesis 3) at pre-exploitation equilibrium – assumed to be 0.5.

(d) For the trials in which there is age-dependency across sub-area 1, estimates of total mortality are generated for sub-areas 1W and 1E+2 ($N(0.864, 0.027^2)$ and $N(0.894, 0.006^2)$ respectively in the years 1971-79 + 2000-03) and the fit to these data included in the objective function used when conditioning the operating model. The model estimate of the survival rate is based on applying the Chapman-Robson estimator to animals aged 15+ for consistency with the way the above normal distributed were derived. The model estimates of the total mortality for sub-areas 1W and 1E+2 are obtained by averaging total mortality by year over year, weighting the yearly estimates by the number of animals aged, i.e.:

$$\hat{M}^A = \sum_y Q_y^A \bar{M}_y^A \Big/ \sum_{y'} Q_{y'}^A \qquad \text{(G.2)}$$

where Q_y^A is the number of animals aged in region *A* (either 1W or 1E+2) during year *y* as given in Table 9, and

$\bar{M}_y^A$ is the total mortality for region *A* and year *y*.

The total mortality for area *A* and year *y* is computed using the Chapman-Robson estimator, i.e.:

$$\bar{M}_y^A = (1 + 1/\tilde{a}_y^A)^{-1} \qquad \text{(G.3)}$$

where $\tilde{a}_y^A$ is the amount by which the average age of the catch during year *y* in region *A* exceeds the age-at-recruitment, i.e.:

$$\tilde{a}_y^A = \sum_a a(C_{y,a}^{\mathrm{m},A} + C_{y,a}^{\mathrm{f},A}) \Big/ \sum_{a'} (C_{y,a'}^{\mathrm{m},A} + C_{y,a'}^{\mathrm{f},A}) \qquad \text{(G.4)}$$

H. Trials

The *Implementation Simulation Trials* for the western North Pacific Bryde's whales are listed in Table 6. All of trials are based on the assumption g(0)=1. Mixing is stochastic (see section E) for the trials in which Stock 1 or Sub-stock 1E is found in sub-area 2. A similar scheme is used to model stochastic mixing of Sub-stocks 1W and 1E in sub-areas 1W and 1E for trials Br13 and Br14.

I. Management Options

The following four management options will be considered.

Management options based on calculating catch limits by *Small Area*:

(1) Sub-areas 1W, 1E[1] and 2 are *Small Areas* and catch limits are set by *Small Area*.

(2) Sub-area 2 is taken to be a *Small Area* and the complete sub-area 1 is treated as a *Small Area.* For this management option, all of the future catches in sub-area 1 are taken from sub-area 1W.

Management options based on applying catch cascading:

(3) Sub-area 2 is taken to be a *Small Area* and sub-area 1 is taken to be a *Combination area*. Sub-areas 1W and 1E are *Small Areas*, with *catch-cascading* applied.

(4) Sub-areas 1 and 2 (combined) are taken to be a *Combination area*, and sub-area 2 and sub-areas in 1W and 1E are *Small Areas*, with *catch-cascading* applied.

The simulation application of the RMP is based on using the "best" catch series (see Table 2).

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[1] Defined to be 140^0E-165^0E and 165^0-180^0 irrespective of the true boundary used to define the structure of the populations in the operating model.

J. Output Statistics

Population-size and continuing catch statistics are produced for each stock/sub-stock and catch-related statistics for each sub-area.

(1) Total catch (TC) distribution: (a) median; (b) 5th value; (c) 95th value.

(2) Initial mature female population size (P_{initial}) distribution: (a) median; (b) 5th value; (c) 95th value.

(3) Final mature female population size (P_{final}) distribution: (a) median; (b) 5th value; (c) 95th value.

(4) Lowest mature female population size (P_{lowest}) distribution: (a) median; (b) 5th value; (c) 95th value.

(5) Average catch by sub-area over the first ten years of the 100 year management period: (a) median; (b) 5th value; (c) 95th value.

(6) Average catch by sub-area over the last ten years of the 100 year management period: (a) median; (b) 5th value; (c) 95th value.

K. References

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Table 1
The mixing matrices. The symbol *x* indicates that the entry concerned is to be estimated during the conditioning process.

	Stock 1	Sub-stock 1A	Sub-stock 1B	Stock 2
SINGLE STOCK HYPOTHESIS (matrix A)				
Sub-area 1W	1	-	-	N/A
Sub-area 1E	γ_1	-	-	N/A
Sub-area 2	γ_2	-	-	N/A
TWO STOCK HYPOTHESIS (matrix B)				
Sub-area 1W	1	-	-	0
Sub-area 1E	γ_2	-	-	0
Sub-area 2	0	-	-	1
TWO STOCK HYPOTHESIS (matrix C1) [note: mixing is stochastic in this trial]				
Sub-area 1W	1	-	-	0
Sub-area 1E	γ_3	-	-	0
Sub-area 2	γ_3^*	-	-	1
	Matrix C2			
Sub-area 1W	1	-	-	0
Sub-area 1E	γ_3	-	-	0
Sub-area 2	0	-	-	1
TWO STOCK HYPOTHESIS (matrix D)				
Sub-area 1W	-	1	γ_6	0
Sub-area 1E	-	γ_5	1	0
Sub-area 2	-	0	0	1

* selected so that the split of the population size at pre-exploitation equilibrium between Sub-stock 1B and Stock 2 in sub-area 2 is 50:50.

Table 2 The three catch series

Table 3 The estimates of abundance and their sampling standard errors

Sub-areas	**Year**	**Estimate**	**Sampling CV**
1W (165 boundary)	1995	8,152	0.329
1E (165 boundary)	1995	10,814	0.342
2	1995	2,860	0.372

Table 4 Sighting survey plan for the western North Pacific Bryde's whales. Note: the results from any surveys in the westernmost part of sub-area 1W are ignored in the trials (see section F).

Season	Sector			
	130°E-145°E	145°E-165°E	165°E-180°	180°-160°W
2006		Yes		
2007			Yes	
2008	Yes			
2009				Yes
2010		Yes		
2011			Yes	
2012	Yes			
2013				Yes
2014		Yes		
2015			Yes	
2016	Yes			
2017				Yes
2018		Yes		
2019			Yes	
2020	Yes			
2021				Yes

Table 5 The values for the biological and technological parameters that are fixed.

Parameter	**Value**
Plus group age, *x*	50 yrs
Natural mortality, *M*	0.08yr^{-1}
Age-at-first-parturition, a_m	7 years (Adjunct 2)
Selectivity (historical)	
Sub-area 1W:	Knife-edged at age 5 (IWC, 2000, 2005)
Sub-areas 1E & 2:	Knife-edged at age 9 (IWC, 2000, 2005)
Selectivity (future)	Knife-edged at age 5 (Item 3.2)
Maximum Sustainable Yield Level, *MSYL*	0.6 in terms of mature female component of the population

Table 6 The *Implementation Simulation Trials* for the western North Pacific Bryde's whales..

Trial No.	**Stocks**	**Sub-stocks**	$MSYR_{\text{mat}}$	**Mixing matrix**	**Process error**	**Stochastic mixing in 1W/1E**	**Catch series**	**Age-dependent Mixing?**	**1W / 1E boundary**	**Comment**	**Trial Weight**
Br1	1	No	1	A	Baseline	No	Best	No	165°E	Stock structure hypothesis 1	M
Br2	1	No	4	A	Baseline	No	Best	No	165°E	Stock structure hypothesis 1	**H**
Br3	2	No	1	B	Baseline	No	Best	No	165°E	Stock structure hypothesis 2	M
Br4	2	No	4	B	Baseline	No	Best	No	165°E	Stock structure hypothesis 2	**H**
Br5	2	No	1	C	Baseline	No	Best	No	165°E	Stock structure hypothesis 3	M
Br6	2	No	4	C	Baseline	No	Best	No	165°E	Stock structure hypothesis 3	**H**
Br7	2	Yes	1	D	Baseline	No	Best	No	155°E	Stock structure hypothesis 4	M
Br8	2	Yes	4	D	Baseline	No	Best	No	155°E	Stock structure hypothesis 4	M
Br9	2	No	1	B	Baseline	No	Best	**Yes**	165°E	B + Age-dependent mixing	M
Br10	2	No	4	B	Baseline	No	Best	**Yes**	165°E	B + Age-dependent mixing	**H**
Br11	2	Yes	1	D	$\sigma_p = 0.9$	No	Best	No	155°E	D + Additional process error	M
Br12	2	Yes	4	D	$\sigma_p = 0.9$	No	Best	No	155°E	D + Additional process error	M
Br13	2	Yes	1	D	Baseline	**Yes**	Best	No	155°E	Stochastic mixing	M
Br14	2	Yes	4	D	Baseline	**Yes**	Best	No	155°E	Stochastic mixing	M
Br15	2	Yes	1	D	Baseline	No	Best	No	**160°E**	Alternative Boundary 1	M
Br16	2	Yes	4	D	Baseline	No	Best	No	**160°E**	Alternative Boundary 1	M
Br17	2	Yes	1	D	Baseline	No	Best	No	**165°E**	Alternative Boundary 2	M
Br18	2	Yes	4	D	Baseline	No	Best	No	**165°E**	Alternative Boundary 2	M
Br19	2	Yes	1	D	Baseline	No	**Low**	No	155°E	D + Low catch series	M
Br20	2	Yes	4	D	Baseline	No	**Low**	No	155°E	D + Low catch series	M
Br21	2	Yes	1	D	Baseline	No	**High**	No	155°E	D + High catch series	M
Br22	2	Yes	4	D	Baseline	No	**High**	No	155°E	D + High catch series	M
Br23	2	No	1	B	Baseline	No	**High**	No	165°E	B + High catch series	M
Br24	2	No	4	B	Baseline	No	**High**	No	165°E	B + High catch series	**H**
Br25	2	No	1	B	$\sigma_p = 0.9$	No	Best	No	165°E	B + Additional process error	M
Br26	2	No	4	B	$\sigma_p = 0.9$	No	Best	No	165°E	B + Additional process error	**H**
Br27	2	No	1	B	Baseline	No	**High**	**Yes**	165°E	B + Age-dep.mixing+high catch	M
Br28	2	No	4	B	Baseline	No	**High**	**Yes**	165°E	B + Age-dep.mixing+high catch	**H**

Table 7 Summary of the Bryde's whales marked in the western North Pacific.
This table ignores 94 animals that were marked outside of sub-areas 1 and 2. To come: no. with 165° boundary

Year	Sub-area		
	1W (155°boundary)	1E (155°boundary)	2
1972	3	0	0
1973	2	7	0
1974	0	8	2
1975	9	6	14
1976	0	2	1
1977	0	0	1
1978	42	7	0
1979	72	5	0
1980	36	18	1
1981	25	7	0
1982	31	9	0
1983	28	24	0
1984	36	34	0
1985	13	0	0
Total	297	127	19

Table 8. a) Marks recovered from Japanese whaling fleets within subareas 1W, 1E and 2.

Mark No	Date marked	Date Recovered	Position Marked	Position recovered	Sex	Length (m)
12065	12 Feb 1972	2 May 1982	24°48N,142°3E	24°25N,144°16E	M	12.6
12198	16 Mar 1973	10 Jun 1976	23°58N,156°40E	29°19N,166°45E	F	14.3
33017	15 May 1978	30 Apr 1981	25°12N,145°11E	29°51N,138°20E	M	13.3
33552	28 Jun 1979	11 May 1980	27°55N,147°46E	32°12N,137°21E	F	13.4
33565	28 Jun 1979	19 Apr 1986	27°57N,147°43E	24°13N,143°46E	M	12.8
33528	28 Jun 1979	10 Jun 1986	27°59N,147°21E	26°29N,143°13E	M	12.9
14622	11 Jun 1980	2 Jun 1981	24°55N,141°43E	25°9N,141°56E	F	12.7
14711	26 Jun 1980	28 Apr 1984	30°6N,152°36E	25°41N,144°19E	M	12.7
14725	28 Jun 1980	1 May 1986	27°18N,157°46E	25°36N,143°54E	F	12.6
14741	29 Jun 1980	21 Jun 1981	25°52N,159°14E	31°35N,142°53E	F	12.9
14776	16 Jun 1981	29 Apr 1984	26°15N,159°55E	25°55N,143°18E	F	12.2
14799	20 Jun 1981	7 Jun 1985	27°29N,150°00E	27°38N,143°17E	F	13.3
37319	21 Jun 1981	18 Apr 1982	27°39N,146°43E	25°17N,142°13E	F	11.5
37322	21 Jun 1981	12 Jun 1985	27°38N,146°34E	26°38N,143°4E	M	12.2
14380	12 Jun 1982	26 Apr 1986	25°3N,149°58E	25°14N,144°11E	M	11.9
14408	18 Jun 1982	21 Apr 1985	27°34N,156°32E	25°19N,143°50E	M	12.4
14476	18 Jun 1983	26 Apr 1986	23°5N,134°0E	25°32N,144°39E	M	12.4
14491	24 Jun 1983	12 Jul 1985	20°1N,139°24E	26°10N,144°57E	F	11.5
14801	28 Jun 1983	9 May 1984	25°28N,144°50E	26°50N,142°56E	M	11.5
14807	30 Jun 1983	14 Jun 1984	23°58N,148°25E	24°33N,142°15E	M	12.4
14994	30 Jun 1984	4 Aug 1985	26°34N,147°31E	26°59N,144°19E	F	12.3
15098	30 Jul 1984	21 Apr 1985	35°9N,146°18E	25°43N,143°34E	M	13.4

Table 9. Sample sizes of aged whales used to calculate mortality rates

(Data using 165° boundary – to be confirmed)

	Year	Subarea 1W	Subareas 1E + 2
Commercial catches			
	1971	0	12
	1972	0	0
	1973	0	1
	1974	0	105
	1975	0	214
	1976	0	92
	1977	0	65
	1978	0	31
	1979	0	126
Scientific permit catches			
	2000	34	0
	2001	25	0
	2002	25	0
	2003	26	0

Adjunct 1

Approximate calculation of Sub-area level additional CVs based on revised abundance estimates for conditioning of IST

H. Okamura, T. Kitakado, and D.S. Butterworth

Sub-area level CVs are calculated based on the method in Annex ??. CVs based on sampling errors were calculated by Tables 2 and 3 (Case 2) of SC/O05/BWI6. For example, the sampling CV for block F, $CV_S(N_F)$, is

$$CV_S(N_F) = \frac{\sqrt{(N_{F,\text{closing}}/R)^2\{CV_S^2(N_{F,\text{closing}}) + CV^2(R)\} + N_{F,\text{passing}}^2 CV_S^2(N_{F,\text{passing}})}}{N_{F,\text{closing}}/R + N_{F,\text{passing}}} .$$

where $R = 0.727$ ($CV(R) = 36.4$ %) [Annex ??]. We ignored a correlation for simplicity.

Then, $\text{var}_S(N_F) = \{CV_S(N_F)\exp(\mu_F + \sigma_F^2/2)\}^2$ where μ_F and σ_F are extracted from Table 1 of Annex ??.

Total $CV_T(N_F) = \sqrt{CV_S^2(N_F) + \sigma_A^2}$ for each block, and $\text{var}_T(N_F) = \{CV_T(N_F)\exp(\mu_F + \sigma_F^2/2)\}^2$.

For Sub-area 1W = F+G+H, the Sub-area level CVs are calculated as follows:

$$CV_S(N_{FGH}) = \frac{\sqrt{\text{var}_S(N_F) + \text{var}_S(N_G) + \text{var}_S(N_H)}}{N_{FGH}} ,$$

$$CV_T(N_{FGH}) = \frac{\sqrt{\text{var}_T(N_F) + \text{var}_T(N_G) + \text{var}_T(N_H)}}{N_{FGH}} ,$$

$$CV_{Add}(N_{FGH}) = \sqrt{CV_T^2(N_{FGH}) - CV_S^2(N_{FGH})} .$$

Table 1. Summary of the sub-area CVs

	Sub-area 1W (blocks FGH)	Sub-area 1E (blocks IJK)	Sub-area 2 (blocks LM)
$\sigma_p = 0.673$			
N	8,152	10,814	2,860
CV(sampling) %	25.43	24.45	32.80
CV(Total) %	46.68	51.59	58.29
CV(add) %	39.15	45.42	48.19
$\sigma_p = 0.9$			
N			
CV(sampling) %			
CV(Total) %			
CV(add) %			

Adjunct 2

Estimation of age-at-maturity for female Bryde's whales

A.E. Punt

Four models were fitted to the data on the maturity-at-age for female Bryde's whales sampled during JARPN II (table 1 of SC/O05/BWI7). The four models are special cases of the following general model:

$$P_a = \left[\frac{\alpha}{1 + \exp[-(a - a_{50})/\delta]}\right]^\beta \qquad \text{(App.3.1)}$$

where P_a is the proportion of animals of age a which are mature,
a_{50} is the age-at-50%-maturity (if α=1 and $\beta = 1$),
δ is the parameter that determines the width of the maturity ogive,
α is asymptotic fraction of animals which are mature, and
β is a shape parameter.

The model is fitted using a binomial likelihood under the assumption that age and maturity determination are exact (i.e. no measurement error).

The following table lists the values for the parameters of Equation App.3.1 for each of the four models and the true age-at-50%-maturity (the age at which a proportion of α/2 animals are mature). Fig. App.3.1 shows the fit of the four models to the available data.

Although the model in which α (but not β) is treated as an estimable parameter provides the most parsimonious representation of the data, the age-at-50%-maturity is robustly estimated to be 6 years. The age-at-first-parturition corresponding to this age-at-maturity is 7 years.

a_{50}	δ	α	β	No. of parameters	$-\ell nL$	Age-at-50%-maturity
5.93	2.07	1	1	2	21.042	5.93 (0.89)
6.21	0.915	0.978	1	3	15.662	6.21 (0.55)
-23.40	2.33	1	212031	3	19.640	5.99 (N/A)
-7.42	1.25	0.999	30066	4	15.619	5.90 (0.51)

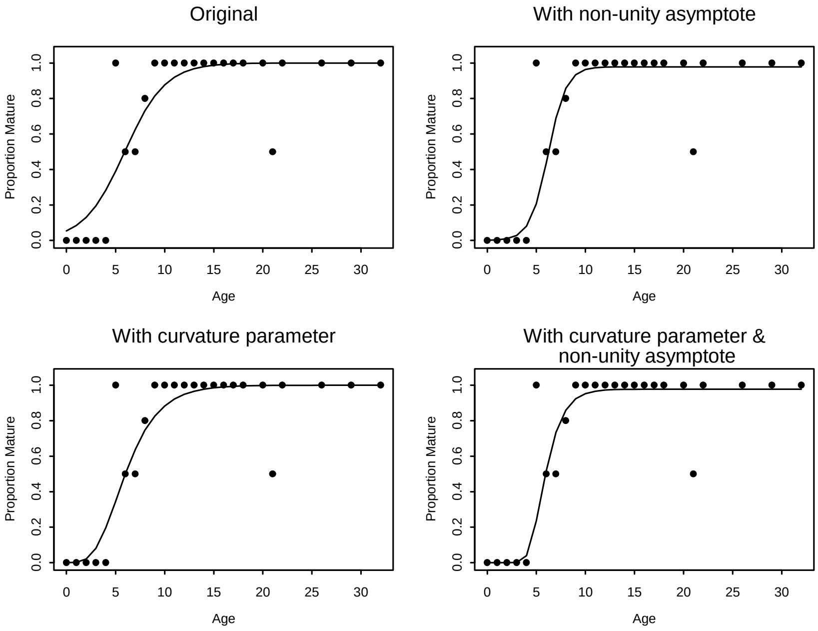

Fig. App.3.1. Fits of the four models to the data on maturity-at-age.

Adjunct 3

The dynamics of tagged animals

The dynamics of tagged animals are essentially the same as those of untagged animals, except that account needs to be taken of tagging. The following equation is used to determine the number of tagged animals of age *a* (for ages less than *x*) and sex *g* in stock/sub-stock *j* at the start of year *t*+1 originally tagged in sub-area *k*, $T^{g,j,k}_{t+1,a}$ (tagging is assumed to take place halfway through the fishing season):

$$T^{g,j,k}_{t+1,a} = [(T^{g,j,k}_{t,a-1}(1-\sum_{k'} V^{j,k'}_{t,a} S^{k'}_{t,a-1} F^{g,k'}_t) + Q^{g,j,k}_{t,a-1}(1-S^{k'}_{t,a-1} F^{g,k}_t/2)]\, e^{-M}\tilde{S} \qquad \text{(App.4.1)}$$

where $Q^{g,j,k}_{t,a}$ is the number of animals of age *a* and sex *g* in stock/sub-stock *j* that were tagged in sub-area *k* during year *t*:

$$Q^{g,j,k}_{t,a} = \frac{Q^k_t\, C^{g,k}_t}{C^{\mathrm{f},k}_t + C^{\mathrm{m},k}_t} \frac{V^{j,k}_{t,a} N^{g,j}_{t,a}}{\sum_{j'} \sum_{a'} V^{j',k}_{t,a'} N^{g,j'}_{t,a'}} \qquad \text{(App.4.2)}$$

Q^k_t is the actual number of releases during year *t* in sub-area *k*; and

$\tilde{S}$ is the rate of tag-loss (assumed to be unity for the baseline analyses).

The number of 'recruits' by age, sex and sub-stock to the tagged population therefore depends on the actual number tagged, assuming that an animal to be tagged is selected at random from the catch. Account is taken in Equation App.4.1 of mortality (both natural and fishing) from the time of tagging until the end of the year.

The observed number of animals recaptured by the Japanese fleets during year *t* in sub-area *k* that were originally tagged in sub-area k', $U^{k,k'}_t$ is given by:

$$U^{k,k'}_t = \Psi\left(\sum_g \sum_j \frac{J^{g,k}_t}{C^{g,k}_t} \sum_a \left[T^{g,j,k'}_{t,a} F^{g,k}_t S^k_{t,a} V^{j,k}_{t,a} + \tfrac{1}{2} F^{g,k'}_t S^{k'}_{t,a} Q^{g,j,k'}_{t,a} \right] \right) \qquad \text{(App.4.3)}$$

where Ψ is the reporting rate parameter (assumed to be independent of sub-area) whose value is estimated during conditioning; and

$J^{g,k}_t$ is the catch of animals of sex *g* in sub-area *k* during year *t* by the Japanese fleets.

The second term in Equation App.4.3 only applies in the case $k = k'$.