A minimum realistic model in the JARPN II offshore survey area

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ABSTRACT

A minimum realistic model (formerly called Mult-spec type model) is under construction for the offshore survey area of JARPN II (The Second Phase of the Japanese Whale Research Program under Special Permit in the western North Pacific) with the system dynamics software that uses difference equations. The final objectives of the model are to forecast the effect of various management options for cetaceans and to make management recommendations including fishery resources that take into account the effect of consumption by cetaceans (minke, sei and Bryde's whales). Pella-Tomlinson model was applied to the cetaceans under MSYR(1+) = 0.02, 0.04 (base case) and 0.06. The abundance values of cetaceans prior to exploitation (K) and at present were estimated on a yearly basis with abundance estimates from sighting surveys and catch series data. Two main prey species of the cetaceans, that were also commercially important (Japanese anchovy and Pacific saury) were age-structured with information from domestic stock assessment. Other supplementary preys (krill, copepoda and others) were included in the model as they had constant biomass with no seasonality. Feeding season of cetaceans was set in May-September and the daily predation was assumed to be equal over the all individual cetaceans to the necessary energy. The proportion of each prey taken by cetacean was calculated from product of the prey biomass, overlap of distribution between prey and cetacean, and prey preference of the cetacean. The overlap of distribution between prey and cetacean was estimated from JARPN II sighting surveys. The estimates of prey preference of the cetaceans were obtained from the JARPN II cooperated whale and prey surveys. Based on the data from 2001 to 2006, the proportion of the preys taken by each cetacean was used for adjusting the parameters of the model. Natural death of Japanese anchovy and Pacific saury was separated into the two parts: the consumption by these cetaceans and the residual natural death. The preliminary results of the model exercises showed that the effect of consumption by the cetaceans to the preys was large for Japanese anchovy, especially in age 0, and limited for Pacific saury.

INTRODUCTION

Historical drastic fluctuations of the pelagic fisheries resources in a process called "species replacement" and severe depletions of many groundfish stocks have occurred in the waters around Japan (Yatsu *et al.*, 2001; Fisheries Agency of Japan, 2008). While these fluctuations and depletions could be attributed to the environmental factors and the effects of fisheries, however, the effect of consumption by cetaceans may not be neglected. Most cetacean resources continue to increase after the introduction of the moratorium on commercial whaling (Hakamada *et al.*, 2004). The usefulness and the need for the multi-species management approaches are discussed in the international organizations (Plagányi, 2007.).

Ecosystem modelling is one of the main objectives of the JARPN II. Three different approaches to the development of the ecosystem modelling are in progress (Kawahara and Hatanaka, 2007); Ecopath with Ecosim (Christensen *et al*., 2000; Mori and Hakamada, 2007; Mori *et al*., 2009) and minimum realistic model (former Multspec-type model: Bogstad *et al*., 1997; Kawahara, 2007) for the offshore region, and a new Bayesian assessment of the effect of marine mammal consumption for the coastal region (Okamura, 2007; Okamura *et al*., 2009). The minimum realistic model is objective-orientated and is considered to be superior to the other models for providing management advices (NAMMCO, 2003; Punt and Butterworth, 1995). Following the basic minimum realistic model developed with EXCEL VBA by Kawahara and Hosho (2004), a more practical model is under construction using the system dynamics software that utilizes data from the JARPN II. The final objectives of the model are to forecast the effect of various management options for cetaceans and to make management recommendations including fishery resources that take into account the effect of consumption by cetaceans. This document describes the specification of the model and reports the recent progress with some preliminary results. To show the overview of the model for the Review, assumed values are used for some parameters in the model.

METHODS

The modelling area is the whole JARPN II survey area except for the bottom layer on the continental shelf. The software used for modelling is STELLA (version 8, Japanese). STELLA is based on difference equations (http://www.iseesystems.com) and has been applied to the ecosystem modelling, for example, in the coastal area off northern Japan (Yamamura, 2004). The basic structure of the minimum realistic model is specified in Appendix 1. The time duration (dt) was set as one month to keep efficiency in calculation and to capture seasonality in the model. An example of the model, which is used for calculating the proportion among preys taken and for separating the consumption by cetaceans from the prey's natural death, is shown in Fig. 1. The most parts around the basic structure are for numerical calculation to check the model behavior.

Pella-Tomlinson model was applied to all baleen whales sampled during the JARPN II (minke, sei and Bryde's whales) with MSYR(1+) = 0.02, 0.04 (base case) and 0.06. The abundance of minke, sei and Bryde's whales prior to exploitation (K) and at present were estimated for each MSYR from fitting to the abundance estimate for the whole stock. The summary of abundance estimates of minke, Bryde's and sei whales in the western North Pacific is shown in Table 1 (Hakamada *et al*., 2009). The estimates with better coverage than others were selected as the abundance for the stock (Table 2). For sei whale, however, estimate of 28369 in 1999 (Hakamada, 2002) was adopted as the base case for the analysis. Other abundance estimates were used to estimate the migration that represent the proportion of animals of the stock in the modelling area by season (Table 3). Catch series of cetaceans are shown in Appendix 2. The first year of catch series was treated as the year for K (1930 for minke whale, 1946 for sei whale and 1911 for Bryde's whale).

Two main prey species of the cetaceans, that are also commercially important (Japanese anchovy and Pacific saury) are age-structured with information on catch, abundance, recruitment, growth etc. cited from the most up-to-date domestic stock assessment (Fisheries Agency of Japan, 2008: Appendix 3). Because the stock assessment was restricted to the coastal part of Japanese anchovy stock, the stock size was expanded to the modelling area from multiplying the correction factor (3.54) based on the data of acoustic surveys under JARPN II in 2004-2006. The virtual coastal stock was introduced in the model to reflect the stock assessment and management in the coastal area. Supplementary preys (krill, copepoda and others) were included in the model as they had the constant biomass with no seasonality. Others were mackerels, sardine, squids etc.

The daily consumption by cetaceans was assumed to be equal over the all individual cetaceans to the necessary energy (Tamura *et al.*, 2009). The daily necessary energy per weight (kcal kg-1) was assumed to be 206.25M^0.783 (Sigurjónsson and Víkingsson, 1997). The average weight (M in the equation) for minke, sei and Bryde's whales were 4.5, 20.4 and 14.0 tons, respectively as in Mori *et al.* (2009). The energy per weight of the preys is shown in Table 4. The feeding season of cetaceans was set from May to September as JARPN II offshore survey has covered the period. The same correction factor of feeding season (2.02) to that in Lockyer (1981) was used for our model as in Tamura *et al.* (2009). The proportion of each prey taken by cetacean was calculated from product of the prey biomass, overlap of distribution between prey and cetacean, and prey preference of the cetacean. The overlap of distribution between prey and cetacean was estimated monthly from dividing the survey area into the 1*1 degree blocks (see Appendix 4). The monthly distribution patterns of cetaceans and preys were constructed from the JARPN II sighting survey data and the rough figures on the distribution described in Fishery Agency of Japan (2008), respectively. The initial values of prey preference of cetaceans in the model were set with reference to estimates obtained from the JARPN II cooperated whale and prey surveys (Murase *et al.*, 2009; Table 5).

Adjustment of the parameters of the model was made mainly with two points: Proportion among preys taken by each cetacean and separation of consumption by the cetaceans from prey's natural death. The period used for adjustment was 2001-2006 as the abundance of cetaceans in the period did not differ among MSYR and the data for the stock assessment of the main preys were improved in the period. For example, the information on the offshore abundance became available for Japanese anchovy from the acoustic surveys under JARPN II after 2004 and for saury from the mid-water trawl survey by the Fisheries Research Agency after 2001. For adjustment with the proportion among preys (and ages in Japanese anchovy and Pacific saury) taken by each cetacean, the comparison between the results obtained from the model and the real stomach contents was made. The diet composition matrix used as the real stomach contents was the same as in Mori *et al.* (2009). The proportion in the model was calculated from summing the consumption of each prey (and ages in Japanese anchovy and Pacific saury) by cetaceans for the five years from 2001-2006. Adjustment was repeated mainly on the prey preference by cetaceans until the proportion among preys by each cetacean became similar to the real stomach contents. For separating the consumption by cetaceans from the prey's natural death, comparison between the natural death with and without consumption by cetaceans was made for Japanese anchovy and Pacific saury by age. The residual natural death was adjusted to be equal to the difference between the original natural death and the consumption by these cetaceans.

RESULTS AND DISCUSSION

The estimates of K and present abundance of cetaceans are shown in Table 2. Examples of fitting the abundance estimates under MSYR(1+) = 0.02, 0.04 and 0.06 are shown in Fig 2. The stock depletions at present (2006) were 0.88-0.95, 0.65-0.97 and 0.81-0.99 for minke, sei and Bryde's whales, depending on MSYR(1+).

For each cetacean, the proportion of preys in the feeding season (May-September) calculated from the model could be well coincided with that in the real data by adjusting mainly the prey preference by cetaceans (Fig. 3). The adjusted final values of prey preference are sometimes different considerably from the initial values from the cooperated whale and prey surveys (Table 5). This is partly due to the problem in the biomass estimates of the preys. For both Japanese anchovy and Pacific saury, the natural death could be separated to the consumption by cetaceans and the residual natural death (Fig. 4). The preliminary results showed that the consumption by three species of cetaceans was more effective for Japanese anchovy, especially age 0, and less effective to Pacific saury.

Although the model exercise showed the large effect of consumption by the cetaceans to Japanese anchovy, there are several uncertainties for the information related to both cetaceans and Japanese anchovy. For example, the correction factor of feeding season (2.02), especially for Bryde's whale, might not be appropriate value to be used in our case. The stock size of Japanese anchovy in the modelling area was expanded from that of the coastal area using the correction factor because the domestic stock assessment was restricted to the coastal area. Furthermore, at present the information on the distribution and migration of preys is incomplete to precisely estimate the overlap with the cetaceans. Similarly, there is a possibility that the consumption of Pacific saury by the cetaceans is underestimated as the feeding season of cetaceans is set short from May to September. In addition to that, the JARPN II surveys did not cover the northern area along the Aleutian Islands and the Kamchatka Peninsula where Pacific saury is distributed in summer. The data for the prey preference are not yet adequate, too. For example, the initial values of preference to krill and copepoda by sei whale were adjusted substantially by the model. Therefore, JARPN II survey should be continued to acquire better data set than we have now to improve the model and then the model will improve the survey to achieve its final objectives. Also, sensitivity analyses should be conducted to forecast the effect of various management options for cetaceans, for example, in the biomass estimates of cetaceans in the modelling area.

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Table 1. Summary of abundance estimates of minke, sei and Bryde's whales in the western North Pacific.

Species	Common minke whale					Sei whale			Bryde's whale			
Stock	O-stock					Western North Pacific			Western North Pacific			
Area	Okhotsk (Russian EEZ), East of Krill Is (Russian EEZ) and high seas (north of 40N, west of 170E)	JARPN II (Area 7-9)		Okhotsk (Russian EEZ)	East of Kuril Is (Russian EEZ) and east of Kamchatka Pen.(Russsian EEZ)	Pacific (30N-55N, 145E-180)	JARPN II (Area 7-9)		10N-43N, 130E-180; 25N-43N, 180-155W.		JARPN II (Area 7-9)	
Abundance	25,049	7,338*	2,976*	28,436	972	68,000	7,744	5,406	21,901	20,501	1,677	9,797
CV	0.315	0.712	0.517	0.185	0.52	0.418	0.27	0.812	0.188	0.366	0.893	0.311
Year	1989-1990	2006-2007		2003	2005	2002-2003	2006-2007		1988-1996	1998-2002	2006-2007	
Season	Aug-Sep	May-June	July-Sep	Aug-Sep		Aug-Sep	May-June	July-Sep	Aug-Sep		May-June	July-Sep
Reference	1	2	2	3	3	7	2	2	4	5,6	2	2

*assuming g(0)=0.732 (CV=0.309) (Okamura et al. 2008)

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Table 2. Estimated K and abundance of minke, sei and Bryde's whales.

Minke whale

MSYR	K(1930)	Survey(1990)	2001	2006	2007
0.02	30300	25049	26800	26700	26700
0.04	27400		26400	26000	25900
0.06	26400		25900	25400	25300

Sei whale

MSYR	K(1946)	Survey(1999)	2001	2006	2007
0.02	46200	28369	28100	30000	30400
0.04	35200		27900	30600	31000
0.06	28900		26700	27900	28000

MSYR	K(1946)	Survey(2003)	2001	2006	
0.02	77300	68000	69000	70900	71200
0.04	69000		68200	68400	68400
0.06	68100		68000	67900	67800

Bryde's whale

MSYR	K(1930)	Survey(2000)	2001	2006	2007
0.02	27000	20501	20700	21800	22000
0.04	22200		20400	21100	21200
0.06	20900		20500	20600	20600

Table 3. Proportion of animals of the stock in the modelling area*

Month	May	June	July	Aug.	Sep.
minke whale	0.293	0.293	0.158	0.158	0.158
Sei whale(28369)**	0.273	0.273	0.191	0.191	0.191
Sei whale(68000)**	0.114	0.114	0.080	0.080	0.080
Bryde's whale	0.082	0.082	0.478	0.478	0.478

*"Migration" is used in the model
**(): abundance estimates for the stock

Table 4. Energy per weight of preys (kcal/kg).

Prey species	Age	kcal/kg
Japanese anchovy	0	1320
	1 and 2	1530
Pacific saury	0	1260
	1	3140
Krill		850
Copepoda		920
Others		1000

(Modified from Tamura et.al)

Table 5. Prey preference of minke, sei and Bryde's whales
Above: estimated initial values from cooperated whale and prey surveys
Below: Final adjusted values

Estimated values

	Japanese anchovy		Pacific saury		Krill	Copepoda	Others
	Year 0	Year 1+	Year 0	Year 1			
Minke whale	0.61*	0.61	1.00		0.09	0.00*	0.05*
Sei whale	0.73*	0.73	0.49		0.31	1.00	0.05*
Bryde's whale	1.00	1.00*	0.49*		0.06	0.00*	0.05*

*tentative value as the estimate is not available in the cooperative whale and prey suveys mainly due to the unoverlapped distribution between the cetacean and the prey

Adjusted values

	Japanese anchovy		Pacific saury		Krill	Copepoda	Others
	Year 0	Year 1+	Year 0	Year 1			
Minke whale	0.00	1.30	0.40	0.70	0.012	0.005	0.60
Sei whale	3.00	0.70	0.005	0.005	0.007	0.007	0.05
Bryde's whale	0.27	4.00	0.00		0.004	0.00	0.03

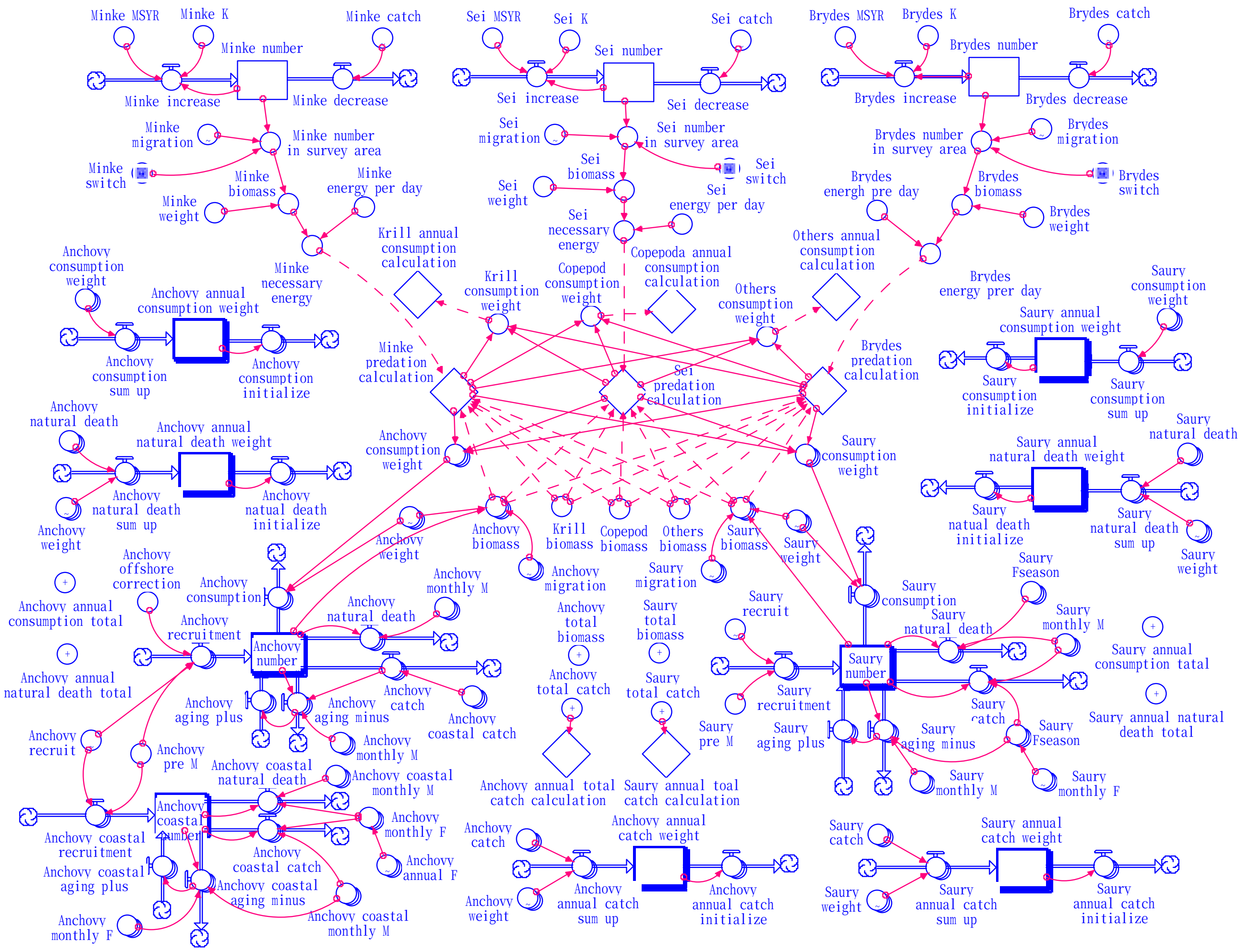


Fig. 1. The structure of the minimum realistic model for calculating the proportion among preys taken and separating the consumption by cetaceans from natural death.

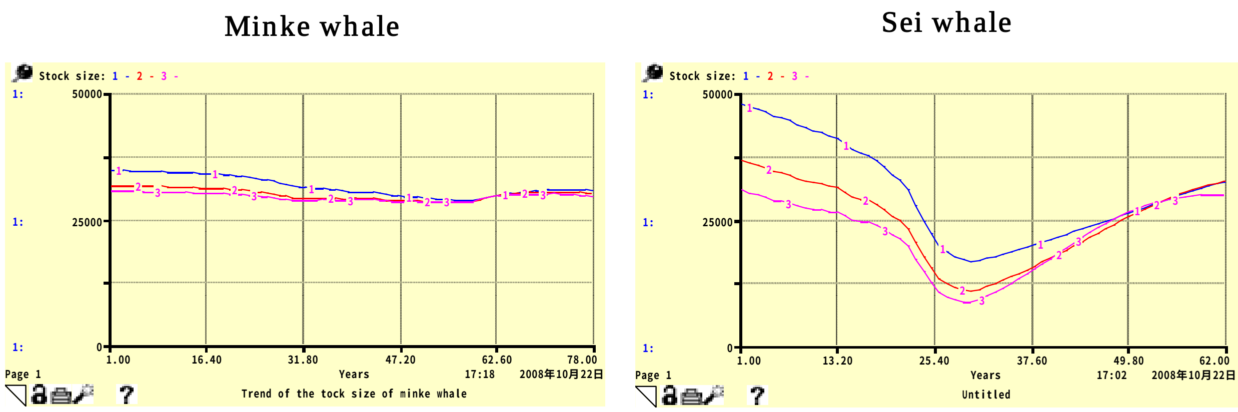


Fig. 2. Examples of estimation of K and present abundance of cetaceans fitting the abundance estimates under MSYR=0.02, 0.04 and 0.06 (left: minke whale, right: sei whale).

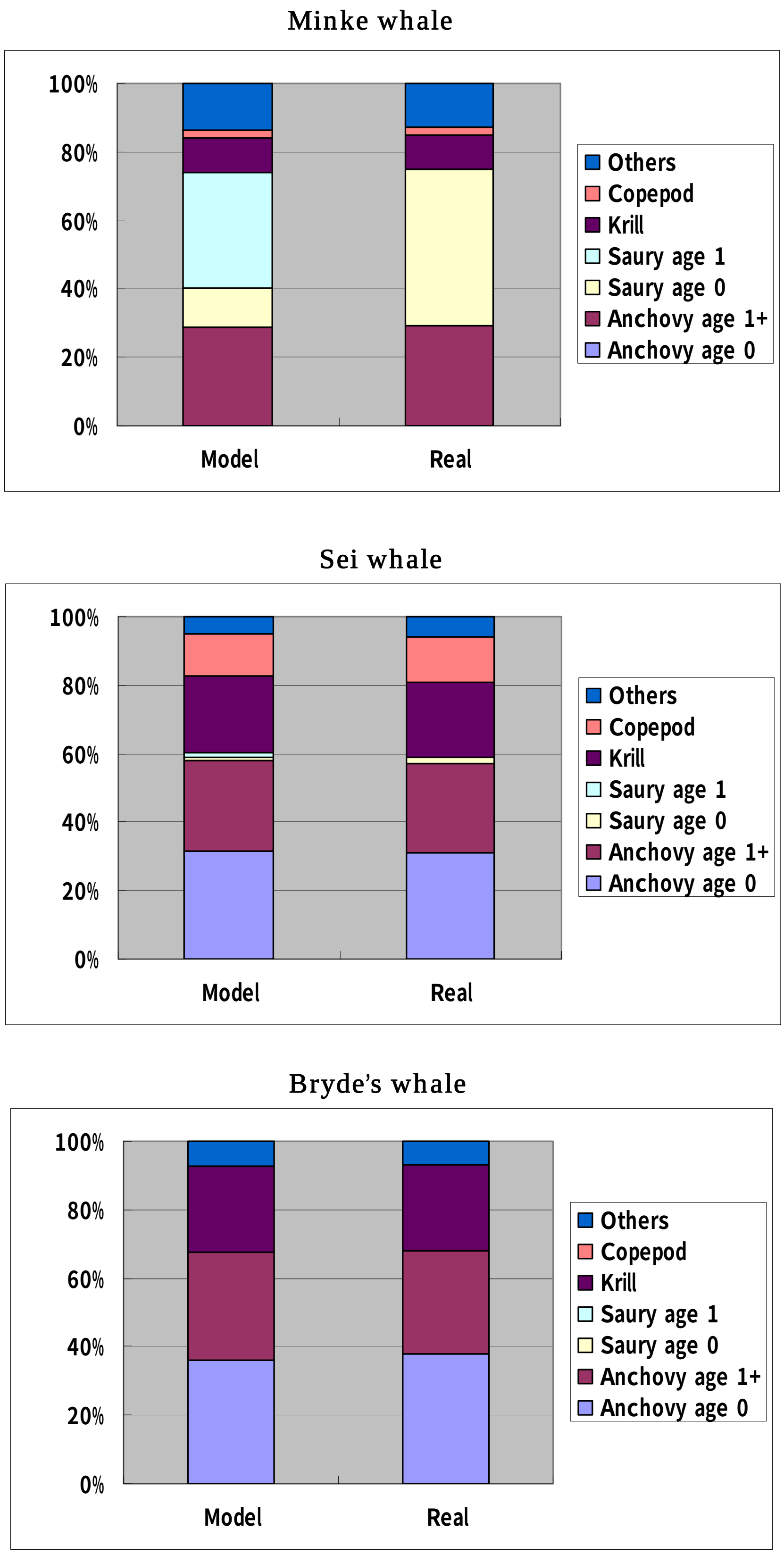
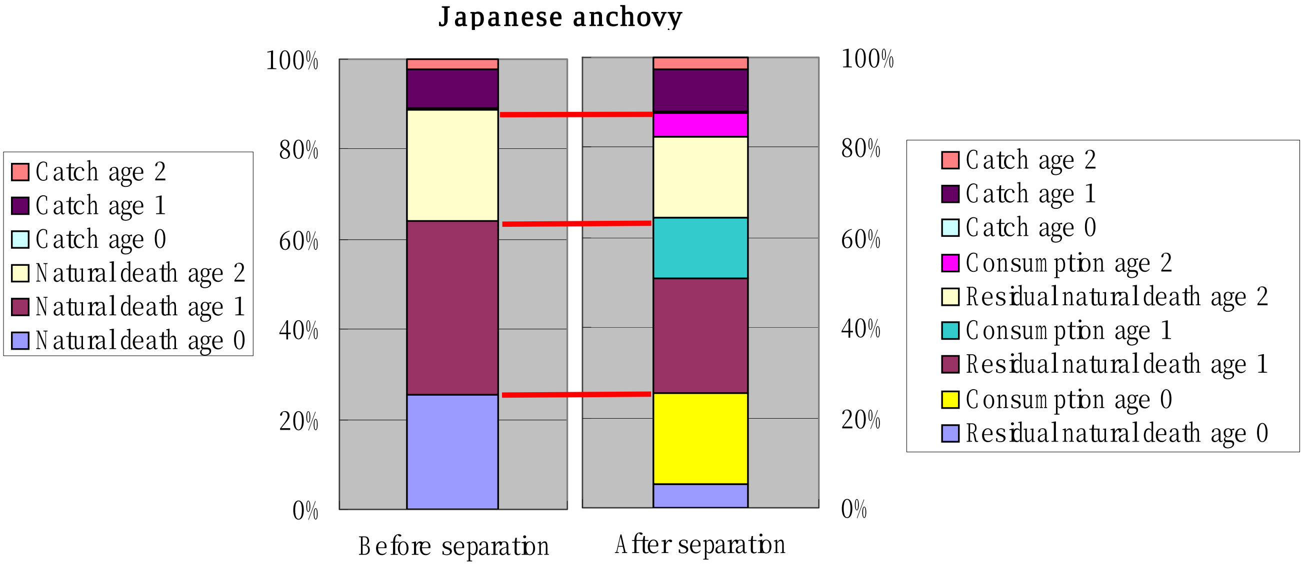


Fig. 3. Comparison of proportion of preys taken by cetaceans between the model and the real data (above: minke whale, middle: sei whale, below: Bryde's whale). Saury in the real data is not divided into the age group.



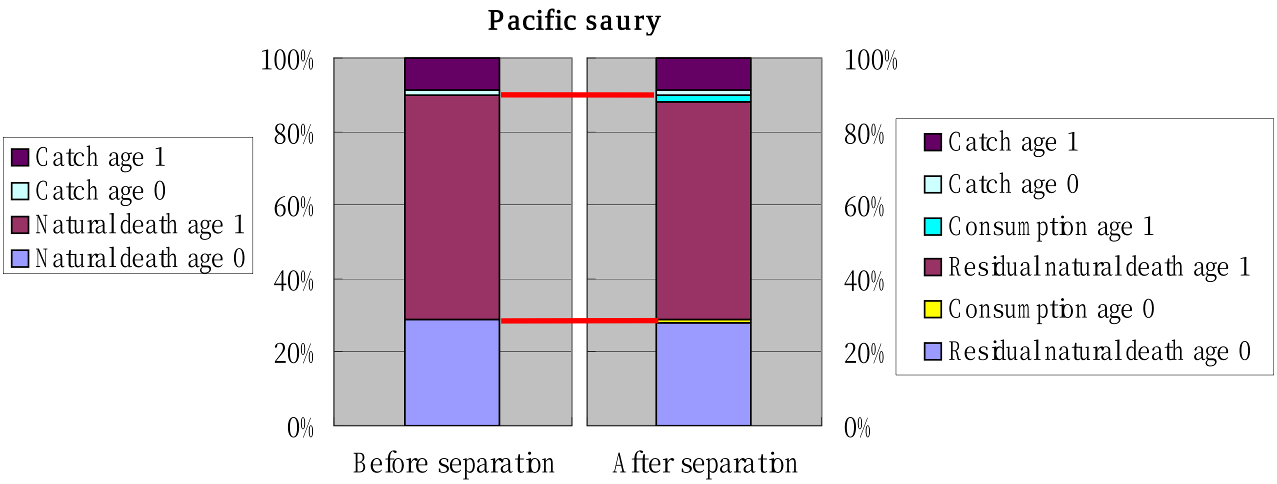


Fig. 4. Separation of natural death into consumption by cetaceans and residual natural death (above: Japanese anchovy, below: Pacific saury)

Appendix 1. Specification of the minimum realistic model for JARPN II

The software used is STELLA (version 8, Japanese). STELLA is the intuitive icon-based graphical interface where difference equations are automatically generated, results are shown in figure/table and sensitivity analyses can be made readily (http://www.iseesystems.com). The basic structure of the model is shown in Fig. 1.

AREA AND TIME DURATION

The modelling area is the whole JARPN II survey area except for the bottom layer on the continental shelf. Calculation is made monthly (dt = one month).

CETACEANS

Pella-Tomlinson model is applied to all baleen whales sampled during JARPN II (minke, sei and Bryde's whales). The example for minke whale is shown below.

Minke_number(t) = Minke_number(t - dt) + (Minke_increase - Minke_decrease) * dt
Minke_increase =
   Minke_number*Minke_MSYR*1.42*(1-(Minke_number/Minke_K)^2.389)   (in April)
Minke_decrease = Minke_catch   (in July)
Minke_biomass = Minke_number_in_the survey_area*Minke_average weight
Minke_necessary_energy = Minke_biomass*Minke_energy_per_day*30
Minke_number_in_the survey_area = Minke_number*Minke_migration

MAIN PREYS

An age-structured model is applied to the two main preys of commercial importance (Japanese anchovy and Pacific saury). The life-span is three and two years for Japanese anchovy and Pacific saury, respectively. The example for Pacific saury is shown below (a=age).

Saury_number[a](t) = Saury_number[a](t - dt) + (Saury_recruitment
        - Saury_natural_death[a] - Saury_catch[a] - Saury_consumption[a]) * dt
Saury_recruitment = Saury_recruit*100*exp(Saury_pre_M*3)   (in April)
Saury_natural_death[a] = Saury_number[a]*Saury_monthly_M[a]/(Saury_Fseason[a]
        +Saury_monthly_M[a)*(1-exp(-Saury_Fseason[a]-Saury_monthly_M[a]))
Saury_catch[a] = Saury_number[a]*Saury_Fseason[a]/(Saury_Fseason[a]
        +Saury_monthly_M[a])*(1-exp(-Saury_Fseason[a]-Saury_monthly_M[a]))
Saury_consumption[a] = Saury_consumption_weight[a]/Saury_weight[a]
Saury_biomass[a] = Saury_number[a]*Saury_migration[a]*Saury_weight[a]

SUPPLEMENTARY PREYS

A simple model with constant biomass (no seasonality) is used for preys of less commercial importance. The biomasses are 110,000 (krill), 60,000 (copepoda) and 3,000 (others: mackerels, sardine, squids etc.) thousand tons, same as Mori *et al.* (2009).

CONSUMPTION

The consumption by cetaceans is assumed to be equal to the necessary energy. The monthly total consumption of a prey is calculated by summing the consumption to the prey by each cetacean. The example of the consumption by minke whale is shown below.

First, total monthly requirement of preys by minke whale is calculated as follow,

Minke_requirement = Minke_necessary_energy/Σ(Minke prey_energy*Minke_prey_%)
Minke_necessary_energy = Minke_biomass*Minke_necessary energy_per_day*30

The proportion of each prey taken by minke whale, for example, in the case of anchovy [age a], is calculated as follows.

Minke_anchovy_%[a] = Minke_anchovy_biomass[a]*Minke_anchovy_preference[a]
*Minke_anchovy_overlap[a]/Minke_all
Minke_all =
Σ(Minke_prey_biomass[a]*Minke_prey_overlap[a]*Minke_prey_preference[a])

Minke_anchovy_overlap[a] is the degree of distributional overlap between minke whale and anchovy[a] (see the Appendix 3). Minke_anchovy_preference[a] is the preference to anchovy [a] by minke whale (see the text).

Finally, the consumption of anchovy [a] by minke whale is calculated as follows,

Minke_anchovy_predation[a] = Minke_requirement*Minke_anchovy_%[a]

Migration is the proportion of animals of the stock in the modelling area

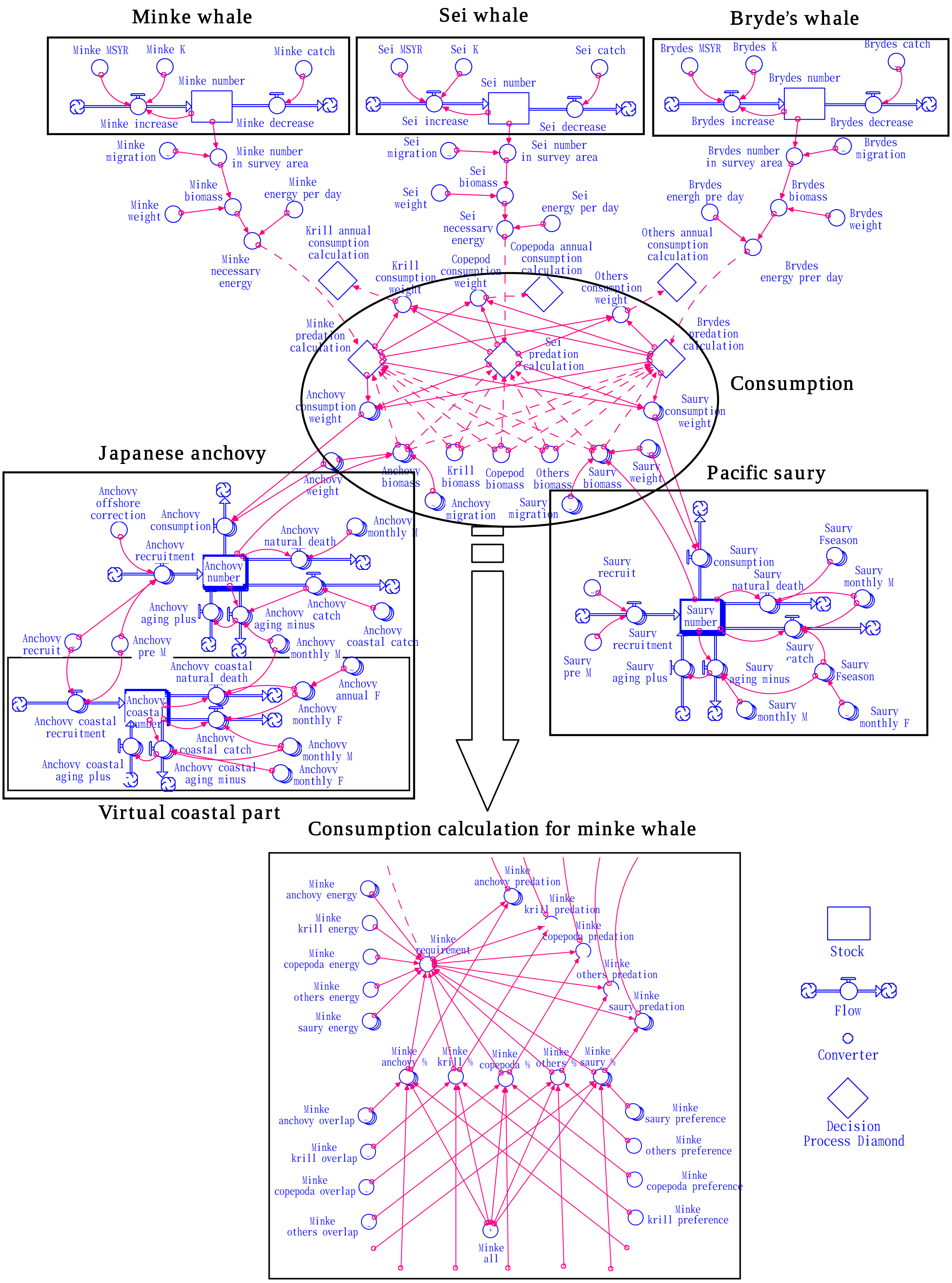


Fig. 1. The basic structure of the minimum realistic model for JARPN II.

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Appendix 2. Catch series of minke, sei and Bryde's whales*

The catches are taken in sub-areas 7, 8, 9, 11 and 12 for minke whale, from the west of 180 for sei whale, and in sub-areas 1 and 2 for Bryde's whale (IWC, 1996; 1997; 2004: Ohsumi, 1971).

Minke whale

Year	Catch	Year	Catch
1930	13	1970	307
1931	13	1971	263
1932	13	1972	337
1933	14	1973	518
1934	24	1974	366
1935	24	1975	328
1936	24	1976	339
1937	57	1977	246
1938	68	1978	400
1939	68	1979	392
1940	79	1980	364
1941	57	1981	358
1942	68	1982	309
1943	101	1983	279
1944	79	1984	367
1945	68	1985	319
1946	96	1986	311
1947	115	1987	304
1948	168	1988	0
1949	134	1989	0
1950	202	1990	0
1951	233	1991	0
1952	293	1992	0
1953	234	1993	0
1954	273	1994	21
1955	374	1995	100
1956	456	1996	77
1957	357	1997	100
1958	516	1998	100
1959	281	1999	100
1960	257	2000	40
1961	333	2001	100
1962	239	2002	150
1963	220	2003	150
1964	289	2004	159
1965	312	2005	220
1966	360	2006	195
1967	270		
1968	214		
1969	213		

Sei whale

Year	Catch	Year	Catch
1946	560	1986	0
1947	466	1987	0
1948	620	1988	0
1949	897	1989	0
1950	500	1990	0
1951	638	1991	0
1952	1102	1992	0
1953	741	1993	0
1954	858	1994	0
1955	644	1995	0
1956	989	1996	0
1957	700	1997	0
1958	1357	1998	0
1959	1543	1999	0
1960	1078	2000	0
1961	866	2001	0
1962	1462	2002	39
1963	1701	2003	50
1964	2118	2004	100
1965	1656	2005	100
1966	2445	2006	100
1967	3661		
1968	3606		
1969	3128		
1970	2768		
1971	1822		
1972	1414		
1973	1073		
1974	748		
1975	302		
1976	0		
1977	0		
1978	0		
1979	0		
1980	0		
1981	0		
1982	0		
1983	0		
1984	0		
1985	0		

Bryde's whale

Year	Catch	Year	Catch
1911	168	1959	263
1912	0	1960	404
1913	0	1961	167
1914	62	1962	504
1915	162	1963	210
1916	90	1964	68
1917	71	1965	8
1918	84	1966	55
1919	78	1967	45
1920	74	1968	171
1921	95	1969	89
1922	84	1970	139
1923	74	1971	919
1924	112	1972	160
1925	120	1973	698
1926	138	1974	1323
1927	116	1975	1433
1928	77	1976	1459
1929	61	1977	946
1930	64	1978	596
1931	135	1979	1028
1932	101	1980	793
1933	92	1981	485
1934	101	1982	482
1935	100	1983	545
1936	96	1984	528
1937	147	1985	357
1938	170	1986	317
1939	204	1987	317
1940	49	1988	0
1941	151	1989	0
1942	21	1990	0
1943	49	1991	0
1944	121	1992	0
1945	11	1993	0
1946	141	1994	0
1947	203	1995	0
1948	197	1996	0
1949	231	1997	0
1950	270	1998	0
1951	304	1999	0
1952	486	2000	43
1953	57	2001	50
1954	70	2002	50
1955	89	2003	50
1956	24	2004	50
1957	39	2005	50
1958	254	2006	50

Appendix 3. Information on Japanese anchovy and Pacific saury

The fish stocks within the EEZ of Japan are assessed annually by Fisheries Agency with the support of Fisheries Research Agency. Following information on Japanese anchovy and Pacific saury was referred from the latest report of the domestic stock assessment (Fisheries Agency of Japan, 2008).

JAPANESE ANCHOVY

Pacific stock of Japanese anchovy is distributed from coastal to offshore waters (Fig. 1). The fisheries are operated throughout the year but the fishing operations are limited to the coastal waters. Recent catches range from 200 to 400 thousands tons. While spawning takes place all the year round except for winter, the main spawning season is now early spring to summer and the recruitment of age 0 fish to the fisheries occurs several months later. For convenience the recruits in January were used in the stock assessment although the recruitment takes place essentially after April. In the model, the values were adjusted to those in April by using the natural mortality rate of age 0 for three months (called pre_M). The fish matures one year old and the life-span is 3 years (A fish gets older at January 1st and lives just 3 years in the model).

Cohort analysis showed recruits and fishing mortality rates (Table 1: only recent years). The stock was at high level but decreasing. Recommended yearly fishing mortality rate as ABCtarget was 1.07 to age 1 for 2008 fishing year. After 5 years the fishing mortality rate would support the lowest spawning biomass in the recent 5 years. In the stock assessment, yearly natural mortality rates applied to were 1.0 for age 0-1 and 1.6 for age 2. Those were estimated empirically with maximum length, growth parameter and water temperature (Pauly, 1980; Quinn and Deriso, 1999). Relationship between age in month and body weight (g): BW = 9.5762t + 3.4685. Recently the information on the offshore biomass became available by the acoustic surveys under JARPN II.

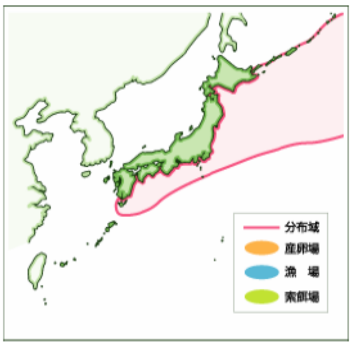

Fig. 1. Distribution of Pacific stock of Japanese anchovy.

Table 1. Recruits in January and fishing mortality rates by age for Japanese anchovy.

Year	Recruits	Fishing mortality rate		
	10^6	Age 0	Age 1	Age 2+
2001	127,952	0.02	0.65	1.75
2002	160,838	0.03	1.33	2.24
2003	154,941	0.02	1.39	3.47
2004	90,294	0.03	1.30	3.02
2005	135,426	0.01	1.08	2.59
2006	92,921	0.02	1.26	3.03

PACIFIC SAURY

Pacific saury is distributed widely in the offshore waters (Fig. 1) and conducts the anticlockwise seasonal migration. The fisheries take place during summer and autumn (Fishing season was set from July to December in the model as in the stock assessment). Recent catches are around 400 thousands tons, half of them are taken by Japan. Main spawning season is winter. As the abundance is available from the June/July mid-water trawl survey, recruitment is treated to occur as the end of June in the stock assessment (Full recruitment was assumed to occur April in the model as predation begins in May). Some fish matures at one year old and the life-span is 2 years (A fish gets older at January 1st in the model).

Based on the June/July mid-water trawl survey, the stock assessment has been made annually (Table 1). Recommended fishing mortality rate for 2008 6-month fishing season is 0.298 to age 1 (multiplied by 0.438 to age 0). The ABCtarget was based on the SPR analysis. The natural mortality rates were estimated as 0.0535 on average by tracing the year class as well as the fishing mortality rates. Relationship between age in day and body weight (g): BW = 200.46(1-exp(-0.004(t+44.79)))^3.

Table1. Recruits in July and monthly fishing mortality rate by age for Pacific saury

Year	Recruits	Fishing mortality rate	
	10^8	Age 0	Age 1
2001	(553)	0.0039	0.0168
2002	945	0.0042	0.0168
2003	329	0.0034	0.0110
2004	631	0.0037	0.0207
2005	481	0.0009	0.0189
2006	381	0.0073	0.0165

( ): an average of 2002-2006

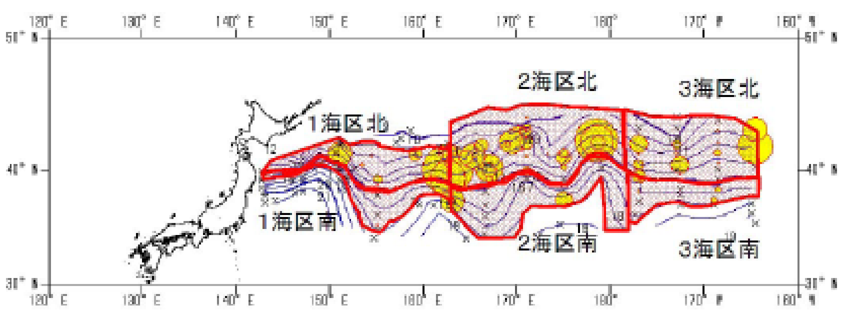

Fig. 1. Distribution of Pacific saury (2007 June/July mid-water trawl survey)

Appendix 4. Overlap of monthly distribution between cetaceans and preys

As one of the factors that decide the proportion of prey taken by a cetacean, the overlap of distribution between cetaceans and preys were analyzed from May to September. The survey area was divided into 1*1 degree blocks and relative density (low: 1, middle: 2, high: 3) was assigned tentatively for cetaceans and preys in each block. Highest relative density (4) was given to the blocks in the main fishing grounds of the preys. Due to the limited data, some extrapolation and assumption were made, for example, to unsurveyed area of cetaceans.

DISTRIBUTION OF CETACEANS

The monthly distribution pattern of cetaceans was estimated with the data from JARPN II sighting surveys. Examples of determination of the pattern are shown in Fig.1. Three species of cetaceans showed the northward movement during the period (Fig. 2). Minke whale was distributed widely from the west to the east and reaches the northernmost part north of 46 N in August/September. It is known that minke whales enter into the Sea of Okhotsk in summer. While the distribution pattern of sei whales was similar to that of minke whales, the summer distribution was limited to the north-eastern part of the survey area. Some Bryde's whales appeared in the southernmost part of the survey area in May. The northern limit of the summer distribution was around 42 N. Those results are well coincide with the past information.

DISTRIBUTION OF PREYS

For Japanese anchovy and Pacific saury, rough figures on the distribution by feeding and spawning seasons are provided by Fishery Agency of Japan (2008). Since 2001 more detailed information on saury has been provided through the June/July mid-water trawl survey covering widely the most western part of North Pacific. The information on the seasonal fishing grounds is available for both Japanese anchovy and Pacific saury. As the information on seasonal movement was limited, the monthly distribution patterns of Japanese anchovy and Pacific saury were assumed mainly with the constant northern sift (Fig. 3). For the supplementary preys (krill, copepoda and others), even distribution was assumed in the modelling area except that relatively high density (middle: 2,) was assigned to krill and copepoda in the coastal and northern areas.

OVERLAP OF DISTRIBUTION

An example of the monthly overlap of distribution between cetaceans and preys is shown for June (Fig.4). The red and grey circles show overlapped and not overlapped blocks, respectively. Minke whale was well overlapped with Pacific saury (age 0 and 1) and Japanese anchovy (age 1+). Sei whale was relatively well overlapped with Pacific saury (especially age 0). Bryde's whale was well overlapped with Japanese anchovy (age 0) but not with Japanese anchovy (age 1+) or Pacific saury. As the input for the model, the degree of overlap was weighted with the assigned density of prey.

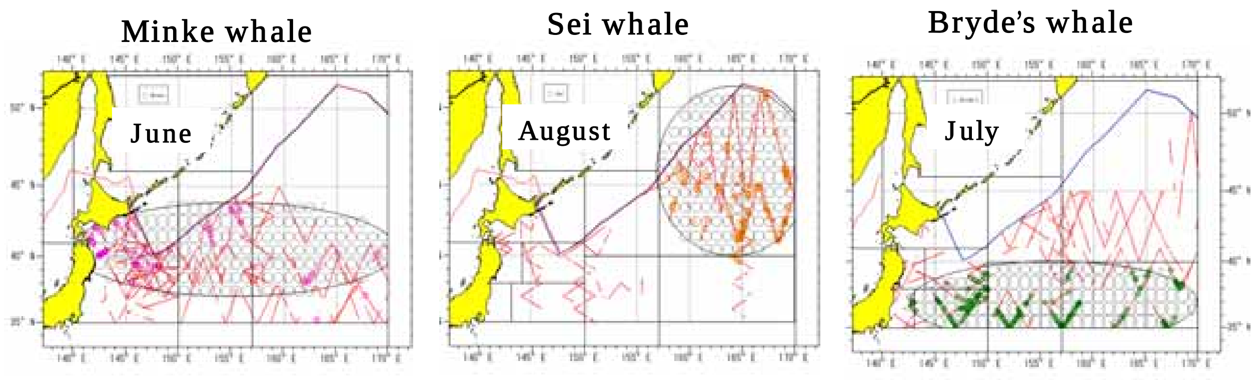

Fig. 1. Examples of determination of the monthly distribution pattern with the data from JARPN II sighting surveys.

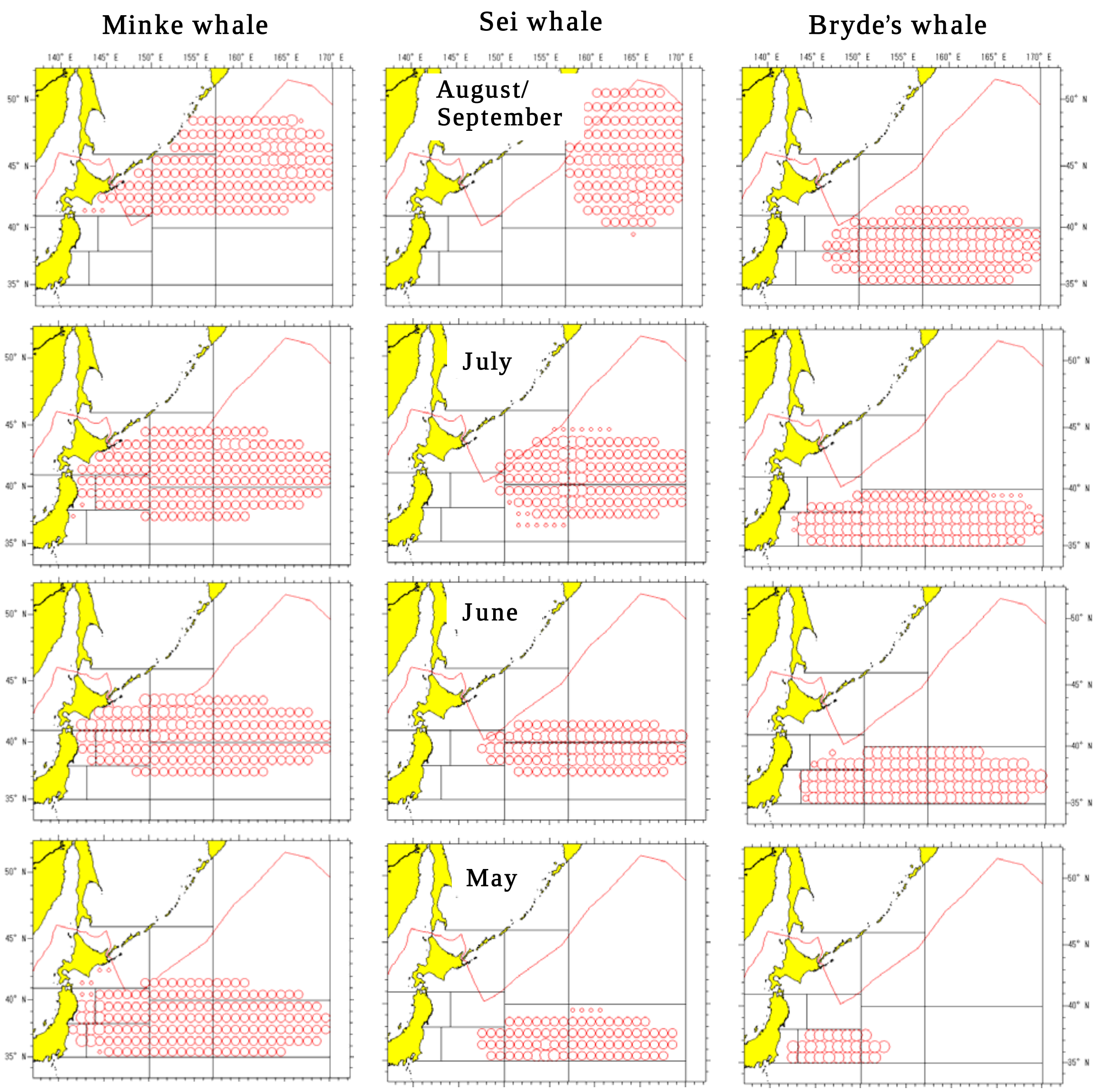

Fig. 2. Monthly distribution pattern of three cetacean species (the size of circle shows the relative density assigned to the block).

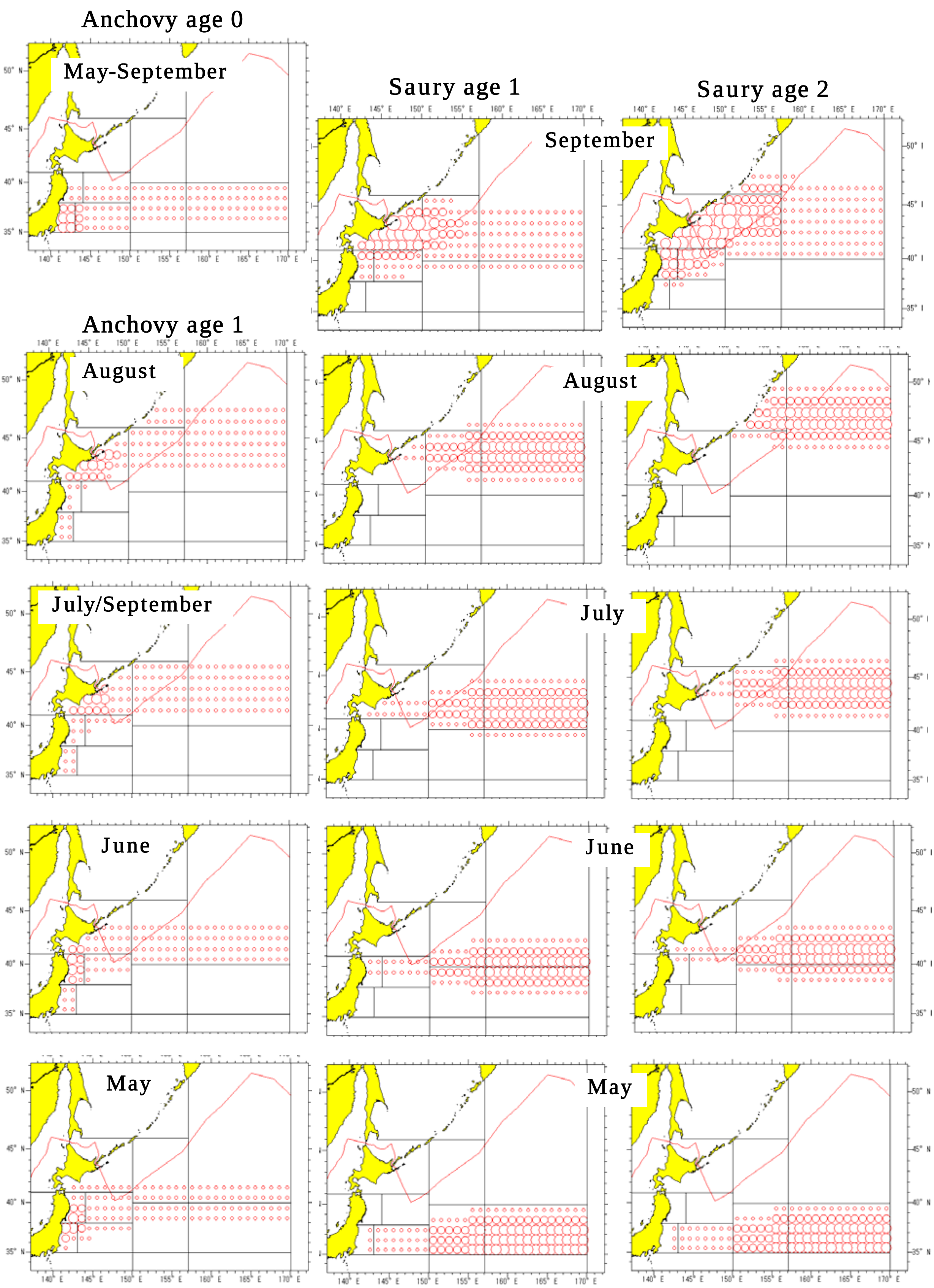

Fig. 3. Monthly distribution pattern of Japanese anchovy and Pacific saury (the size of circle shows the relative density assigned to the block).

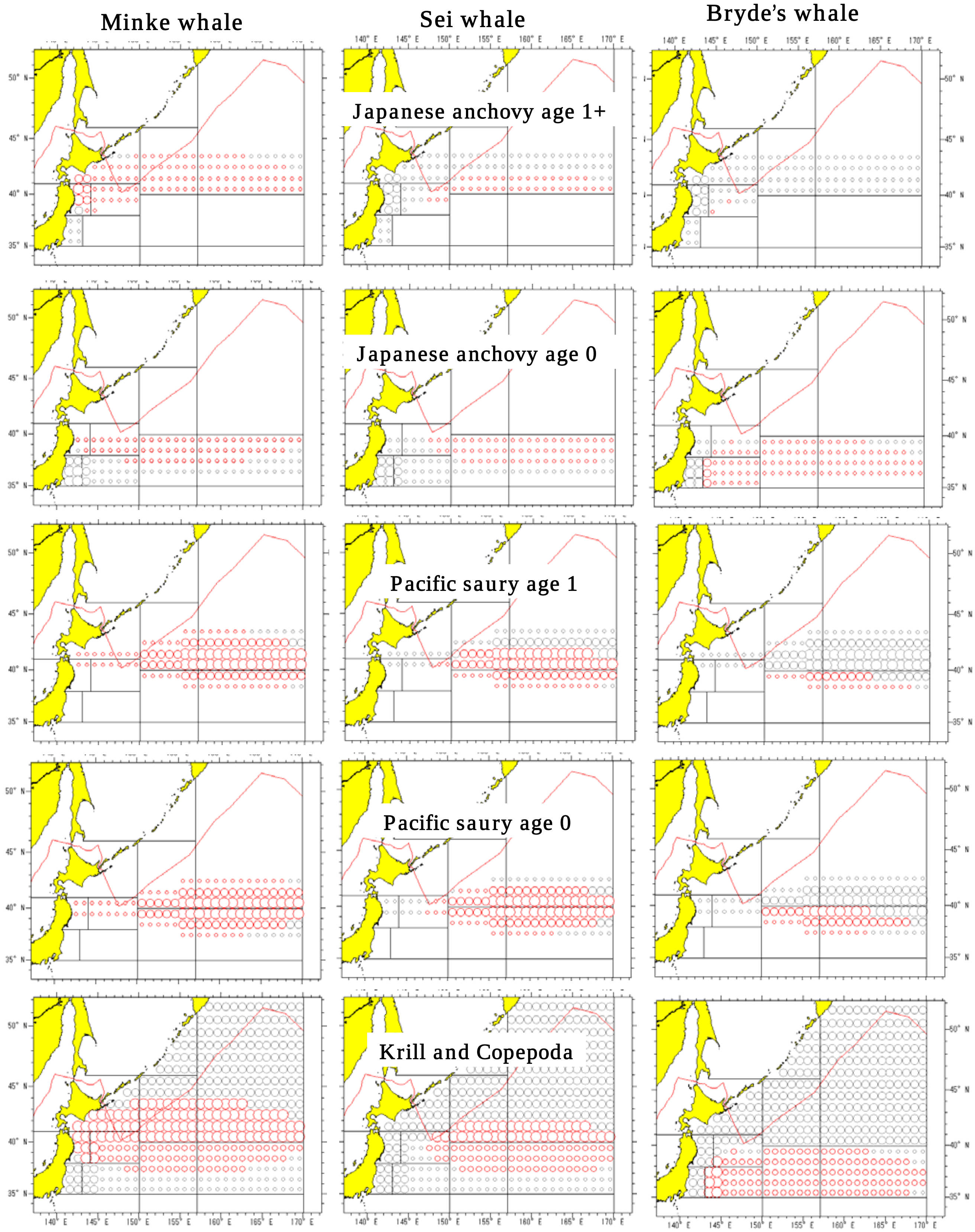

Fig. 4. Examples of the overlap of distribution between cetaceans and preys in June (red circle: overlapped, grey circle: not overlapped). The size of circle shows relative density assigned to the block.