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What do we know about whales and the ecosystem in the western North Pacific Ocean? Part 5: Summary of results on whale's ecology including feeding habitat and ecosystem modelling

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ABSTRACT

The Institute of Cetacean Research has conducted whale research under special scientific permit in the western North Pacific since 1994. The research was conducted systematically under different research programs such as JARPN and JARPNII, and finally, under the NEWREP-NP. These research programs employed both lethal and non-lethal methods to study different aspects of the biology and ecology of large whales in the western North Pacific. NEWREP-NP ceased after the 2019 summer season following Japan's decision to withdraw from the International Convention for the Regulation of Whaling and to start commercial whaling within its Exclusive Economic Zone. This paper summarizes the most relevant ecological research outputs from the Japanese whaling under special scientific permit in the western North Pacific.

INTRODUCTION

Japan conducted systematic research on whales and the ecosystem in the western North Pacific for more than 30 years (1994–2019). The first research program was the Japanese Whale Research Program under Special Permit in the North Pacific (JARPN: 1994–1999), which was followed by JARPNII (2000–2016) and subsequently by the New Scientific Whale Research Program in the North Pacific (NEWREP-NP: 2017–2019). The Institute of Cetacean Research (ICR) was the institution in charge of designing and implementing those research programs. Tamura *et al.* (2017) provided details on the objectives, sampling and analytical methodology of these research programs. Several international review workshops (e.g. IWC, 2001; 2016) discussed and evaluated the large amount of data and results from those research programs.

Following the change in Japan's whaling policy, NEWREP-NP ceased from 30 June 2019, the date of Japan's withdrawal from the International Convention for the Regulation of Whaling (ICRW). At this point, it was considered important to summarize the knowledge on whales and the western North Pacific ecosystem accumulated so far by the Japanese whale research in the North Pacific Ocean.

The objective of this paper is to summarize the most relevant ecological research outputs from the Japanese whaling under special scientific permit in the western North Pacific.

SURVEYS, DATA AND SAMPLES

Surveys were conducted in the western North Pacific, in the sub-areas used by the International Whaling Commission (IWC) for the management of common minke whales (*Balaenoptera acutorostrata*) (Figure 1). The research area on the Pacific side of Japan (e.g. Sanriku and Kushiro) can be considered as Japan's richest fishing grounds and

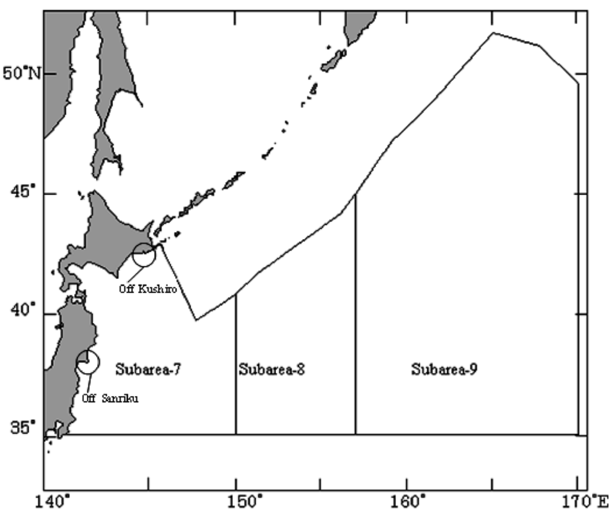

Figure 1. Sub-areas in the western North Pacific used by the IWC for management purposes of the common minke whale. These sub-areas were used for the Japanese whale surveys under special scientific permit.

provided an ideal area to study the interaction between cetaceans and fisheries. This area can be considered as a ʻhot-spotʼ area for cetacean/fisheries interaction.

Survey and sampling methodologies of the Japanese whale research programs in the North Pacific Ocean regarding feeding ecology research were described in Tamura *et al.* (2016). A list of relevant data and samples collected by the Japanese whale research programs in the North Pacific Ocean is available in Tamura *et al.* (2016).

ABUNDANCE ESTIMATES OF LARGE BALEEN WHALES

Apart from its application for assessment and management, abundance estimate information is highly important for evaluating the impact of prey consumption by whales on the ecosystem. Abundance estimates are obtained by analyzing sighting data collected during dedicated sighting surveys. From the results of the feeding ecology studies, prey species of whales are different between the early (May–June) and late (July–September) seasons. For this reason, the abundances were estimated for the early and late seasons. Table 1 shows the abundance estimates for each whale species studied in the western North Pacific. Prey consumption of whales were estimated for the coastal areas of Sanriku and Kushiro as well for the offshore waters of sub-areas 7, 8 and 9. In the latter, abundance was estimated for the early and late seasons as explained above (Table 1). With this information, individual prey consumption can be extrapolated to obtain the amount of consumption by the total number of whales in the area.

DISTRIBUTION OF LARGE WHALES

Analyses of seasonal and spatial distribution of common minke, sei (*B. borealis*) and Brydeʼs (*B. edeni*) whales in the sub-areas of Figure 1 using Generalized Additive Models (GAM) indicated that all species shifted their distribution toward the north as the season progressed from spring to summer. However, the extent of the shift was different among whale species. While spatial segregation occurred among the three baleen whale species, some overlaps occurred. Given this, the extent of direct interaction among whale species could be minimal although indirect interaction could occur as they share the same prey species (Figure 2) (Murase *et al.*, 2016a).

OVERVIEW OF OCEANOGRAPHY, PREY SPECIES DISTRIBUTION AND BIOMASS AND PREY PREFERENCE STUDIES

Oceanography

Oceanographic surveys are important in understanding the pattern of distribution of prey species of whales. The northern part of the survey area is under the influence of the Oyashio (a subarctic western boundary current with cold, low-salinity water) whereas the southern part is under the influence of the Kuroshio and its extension (the subtropical western boundary current with warm, high-salinity water). The area between the Oyashio and the Kuroshio is called the Kuroshio–Oyashio or subarctic-subtropical transition (interferential) zone (Figure 3).

Oceanographic conditions in the research area were examined using FRA-ROMs data. This is an ocean forecast system developed by Fisheries Research Agency (FRA) based on Regional Ocean Modeling System (ROMS). Annual mean PDO index from 1900 to 2015 was calculated using monthly data available from "http://research.jisao.washington.edu/pdo/" [accessed on 6 October 2015]. Negative values of annual mean PDO index were dominant in the period from 2000 to 2013 (Figure 4). It can be considered that JARPNII surveys from 2000 to 2013 were conducted in the negative phase of PDO index.

Prey distribution and prey preference

Prey distribution and prey preferences of common minke, Brydeʼs and sei whales at meso-scale were estimated using data from the cooperative surveys of cetacean sampling and prey of cetaceans (using echosounder and several trawl nets). The surveys were conducted as a part of the offshore component of JARPNII in the western North Pacific from 2002 to 2007 (Figure 5).

For example, in the post-stratified block 1 in 2007, prey distribution, sighting positions and stomach contents of sampled common minke, Brydeʼs and sei whale, water temperature at 100 m and 200 m are shown in Figure 6. All blocks were examined for prey preference of whales.

The standardized form of Manlyʼs selection index called Manlyʼs α, also known as Chessonʼs index, was used for estimating prey preference. Table 2 showed the average Manlyʼs α of three baleen whale species in the JARPNII offshore component survey area in summer seasons from 2002 to 2007. As a result, common minke whales showed preference for Japanese anchovy and Pacific saury while they avoided krill. Brydeʼs whales showed preference for Japanese anchovy while they also avoided krill. Sei whales showed preference for copepods and Japanese

Table 1

Abundance estimates for several large baleen whale species based on dedicated sighting surveys in coastal and offshore waters (from Tamura *et al.*, 2019).

Area: Coastal Sanriku
Species: Common minke whale

Period	Numbers	CV	95% CI LL	95% CI UL
2005	401	0.321	217	741
2006	216	0.407	101	466
2012	124	0.385	121	521

Area: Coastal Kushiro
Species: Common minke whale

Period	Numbers	CV	95% CI LL	95% CI UL
2002	551	0.350	283	1,073
2003	888	0.406	413	1,908
2004	338	0.352	173	660
2005	290	0.350	149	564
2006	221	0.351	113	431
2007	130	0.553	47	358
2012	433	0.542	160	1,171

Area: Offshore sub area 7
Species: Common minke whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2000–2007	4,969	0.934	1,052	23,457
2008–2014	269	0.951	56	1,297
Late				
2000–2007	665	0.667	203	2,182
2008–2014	—	—		

Species: Bryde's whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2000–2007	804	1.593	89	7,280
2008–2016	2,595	0.445	1,128	5,967
Late				
2000–2007	3,090	0.456	1,318	7,245
2008–2016	3,394	0.486	1,376	8,369

Species: Sei whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2002–2007	668	0.529	253	1,768
2008–2016	364	0.938	77	1,729
Late				
2002–2007	241	1.148	40	1,452
2008–2016	60	1.130	10	353

Area: Offshore sub area 8
Species: Common minke whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2000–2007	769	0.636	245	2,411
2008–2014	755	0.738	207	2,747
Late				
2000–2007	226	0.746	61	832
2008–2014	—	—		

Species: Bryde's whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2000–2007	535	1.296	76	3,742
2008–2016	—	—		
Late				
2000–2007	2,918	0.466	1,224	6,958
2008–2016	2,733	0.467	1,145	6,526

Species: Sei whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2002–2007	2,341	0.334	1,237	4,431
2008–2016	614	0.683	182	2,064
Late				
2002–2007	1,400	0.541	518	3,780
2008–2016	908	0.635	290	2,840

Area: Offshore sub area 9
Species: Common minke whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2000–2007	1,600	0.577	560	4,574
2008–2014	2,605	0.701	754	9,000
Late				
2000–2007	2,085	0.618	684	6,362
2008–2014	3,080	0.677	924	10,266

Species: Bryde's whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2000–2007	338	0.732	93	1,220
2008–2016	363	0.441	159	828
Late				
2000–2007	3,790	0.582	1,315	10,920
2008–2016	7,179	0.358	3,636	14,173

Species: Sei whale

Period	Numbers	CV	95% CI LL	95% CI UL
Early				
2002–2007	4,735	0.371	2,340	9,579
2008–2016	3,756	0.182	2,636	5,353
Late				
2002–2007	3,765	0.352	1,928	7,352
2008–2016	4,119	0.444	1,793	9,460

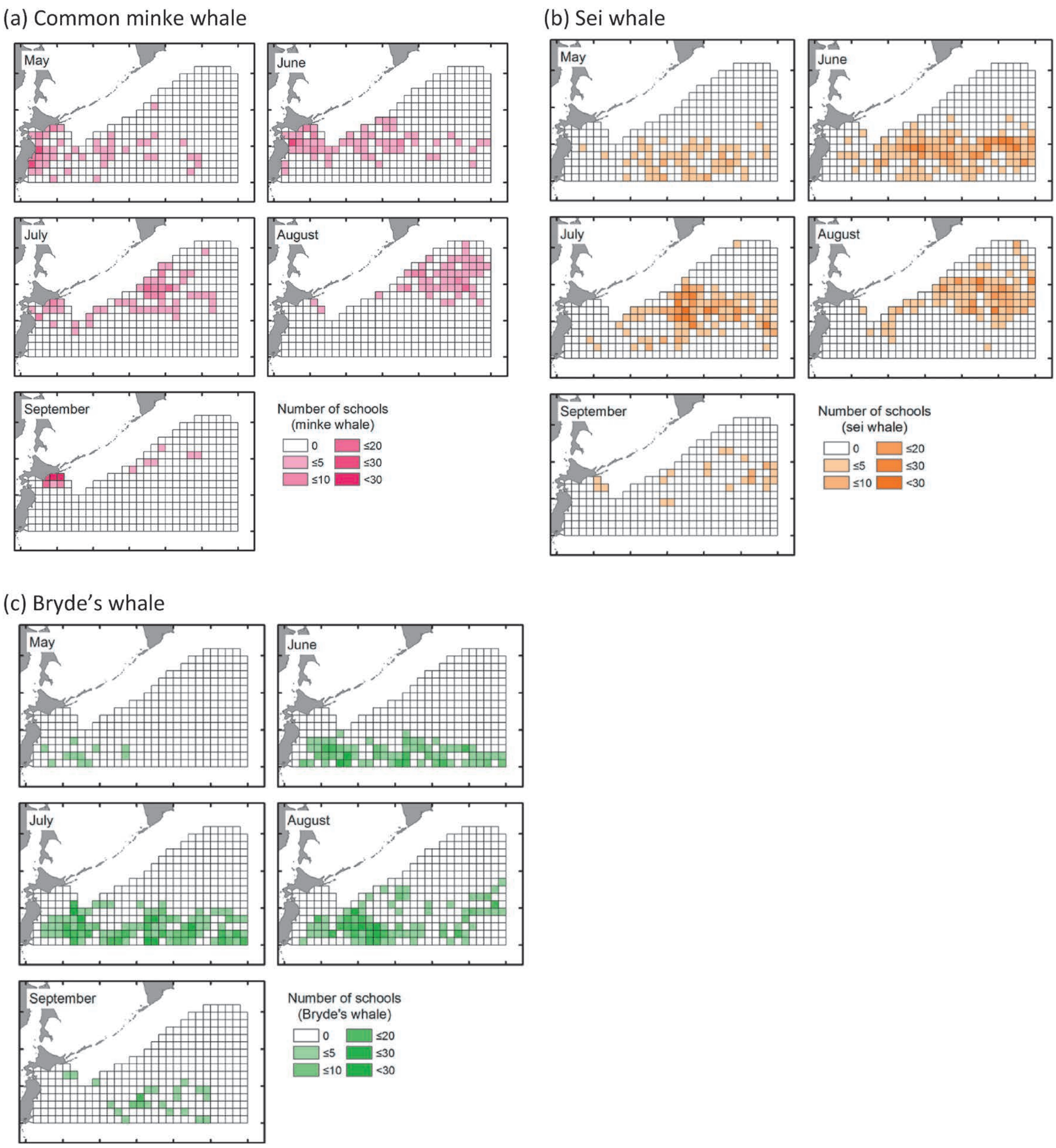

Figure 2. Number of sighted schools of common minke (a), sei (b) and Bryde's (c) whales in 1×1 longitude and latitude grids from May to September. Total numbers from 2002 to 2013 are shown (from Murase *et al.*, 2016a).

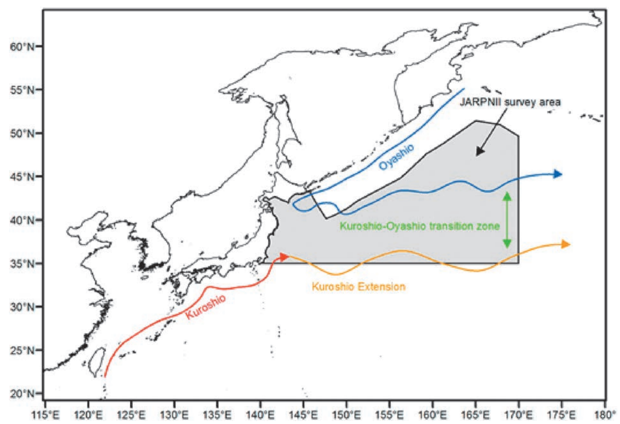

Figure 3. Schematic map of oceanographic structure in the survey area (from Okazaki *et al.*, 2016).

anchovy while they avoided krill and Pacific saury.

Overview of Prey Biomass Studies

In Japan, fish abundance and biomass for species such as Japanese anchovy, Japanese sardine, mackerels and walleye pollock have basically been estimated by cohort analysis. Estimation of the biomass of prey species using a quantitative echosounder in JARPNII were also used.

In offshore waters, basin-scale distribution pattern and biomass estimation of Japanese anchovy, which was one of the main prey species, were examined using a quantitative echosounder between 2004 and 2007. Taking account of the spatial coverage of the survey each year, the most reliable biomass estimate of Japanese anchovy for this region was 3.4 million tons (CV=0.22) (Murase *et al.*, 2012). As an example, Figure 7 shows the distribution of Japanese anchovy in 2006 using a quantitative echosounder.

In coastal waters off Sanriku, the prey surveys were included in the coastal component of JARPNII. The survey area for prey species was divided into ten blocks (A–J) based on bottom depth (20, 40, 100 and 200 m) and prefectural boundary (between Miyagi and Fukushima prefecture) (Figure 8). The biomass of sand lance and Japanese anchovy were examined using a quantitative echosounder between 2005 and 2009. The biomass estimations of sand lance were between 2,827 tons and 28,340 tons. The biomass estimations of Japanese anchovy were between 0.20 and 9,060 tons, respectively (Table 3) (Murase *et al.*, 2009b; Wada *et al.*, 2016).

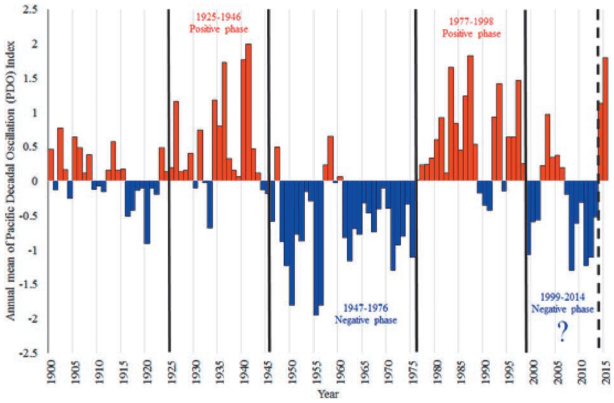

Figure 4. Annual mean of Pacific Decadal Oscillation (PDO) index from 1900 to 2015. Monthly PDO data available from "http://research.jisao.washington.edu/pdo/" (accessed on 6 October 2015) are used to calculate annual mean. Climate regime shift indicated in several published papers are also shown in the figure (see Okazaki *et al.*, 2016).

FEEDING ECOLOGY OF LARGE BALEEN WHALES

Sampling and treatment of stomach contents

Baleen whales have a four chambered stomach system. The stomach contents remain in the forestomach (first stomach) and fundus (second stomach). For the analyses, and after capture, the stomach contents were removed from each compartment and weighed to the nearest 0.1 kg on the ship's flensing deck.

The analysis of prey consumption was based on data collected from the forestomach and fundus. A sub-sample (1–5 kg) of stomach contents was removed and frozen and/or fixed with 10% formalin water for later analyses. The stomach contents were transferred to a system consisting of three sieves (20 mm, 5 mm and 1 mm), which were applied in the Norwegian scientific research to filter off liquid from the rest of the material (Haug *et al.*, 1995). In the laboratory, prey species in the sub-samples were identified to the lowest possible

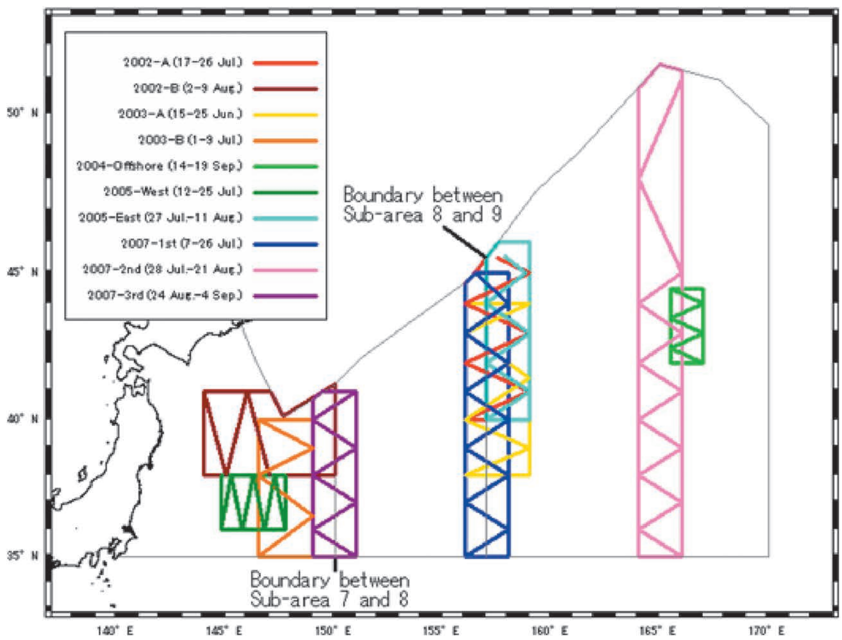

Figure 5. Pre-defined survey blocks for the cooperative whale and prey surveys in JARPNII offshore component from 2002 to 2007. Each color represents boundary of surveyed blocks. These blocks were post-stratified based on observed oceanographic conditions. Zigzag lines within each block represent planned track lines of prey surveys (from Murase *et al.*, 2009a).

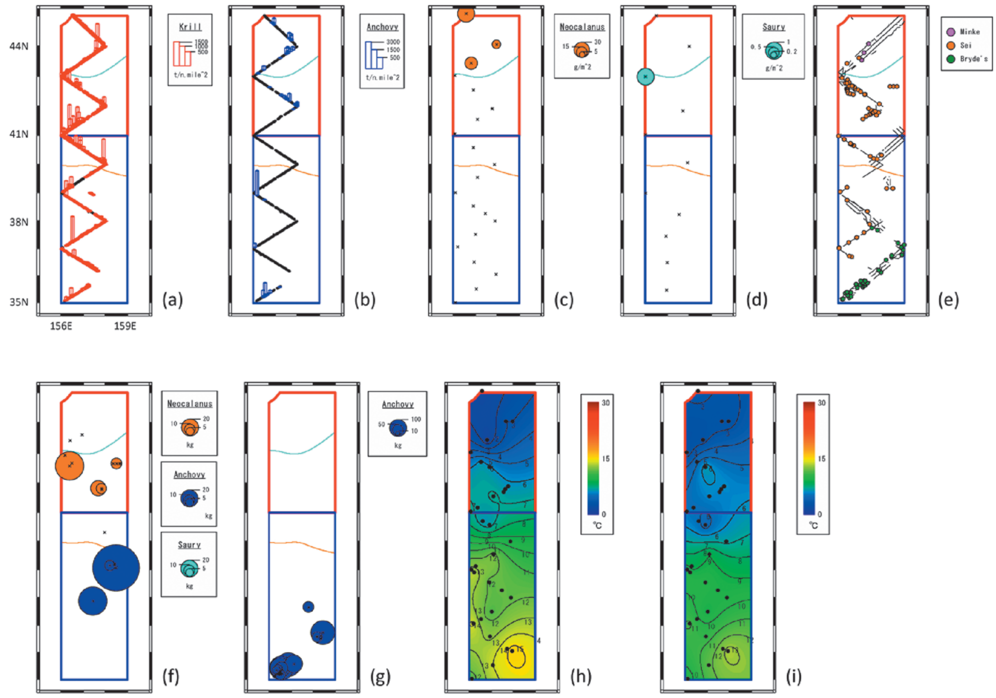

Figure 6. Maps in block 1 in 2007: Distribution patterns of krill (a), Japanese anchovy (b), copepods (*Neocalanus* spp. (Copepodite stage 5)) (c) and Pacific saury (d). Sighting effort and sighting positions of common minke, Bryde's and sei whales (e). Sampled positions and stomach contents of common minke (f) and sei (g) whales. Water temperature at 100 m (h) and 200 m (i) water depth. Encircled areas by red and blue lines are the post-stratified area, E–N and E–S, respectively. Light blue and orange lines in maps (a)–(g) represent 4°C and 10°C isotherm at 100 m water depth, respectively (from Murase *et al.*, 2009a).

Table 2

Estimated average values of Manly's α of common minke, Bryde's and sei whales α in the JARPNII offshore component survey area in summer from 2002 to 2007 using the log-likelihood function based on a multinomial distribution (from Murase *et al.*, 2009a).

Species	Copepods		Krill		Japanese anchovy		Pacific saury	
	Manly's α	SE	Manly's α	SE	Manly's α	SE	Manly's α	SE
Common minke whale	—	—	0.05	0.03	0.36	0.19	0.59	0.17
Bryde's whale	—	—	0.05	0.04	0.95	0.04	—	—
Sei whale	0.41	0.10	0.13	0.04	0.25	0.10	0.20	0.08

taxonomic level. The total weight of each prey species in the stomach contents were estimated by using the values obtained from the sub-sample and the total weight of stomach contents (see details in Tamura *et al.*, 2019).

Data analyses

An estimate of the daily prey consumption by whales requires the use of some additional biological and morphometric data. For example, body length of the whales was measured to the nearest 1 cm from the tip of the upper jaw to the deepest part of the fluke notch in a straight line. Body weight was measured to the nearest 50 kg using large weighing machine. Furthermore, energy requirements are different for sexual maturity classes, and therefore, estimations of the daily prey consumption took into consideration information on sexual maturity. Sexual maturity of each whale was defined by either testis weight or examination of ovaries.

The daily amount of prey consumption consumed is estimated using theoretical energy requirement formulae. The total seasonal prey consumption by whales was estimated using the information on abundance in Table 1, sexual maturity composition, daily prey consumption and a seasonal feeding period of 150 days. The uncertainties associated with the relevant parameters were treated by Monte Carlo simulations (see details in Tamura *et al.*, 2019).

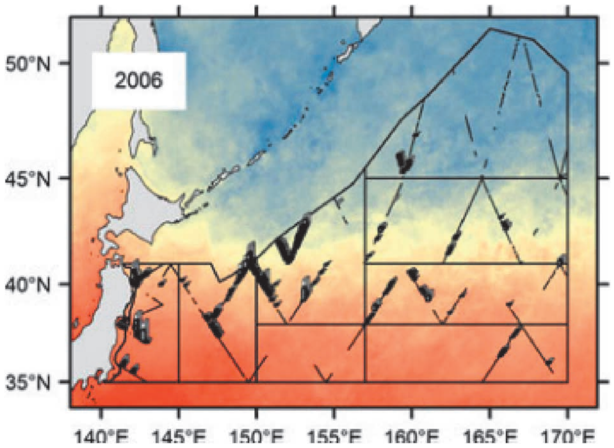

Figure 7. Distribution patterns of Japanese anchovy in 2006. *Bars* Relative densities of anchovy. *Thin black lines* Surveyed track lines. Seasonal composite surface seawater temperature (SST) data in the summer, derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the satellite, Aqua, are also shown (from Murase *et al.*, 2012).

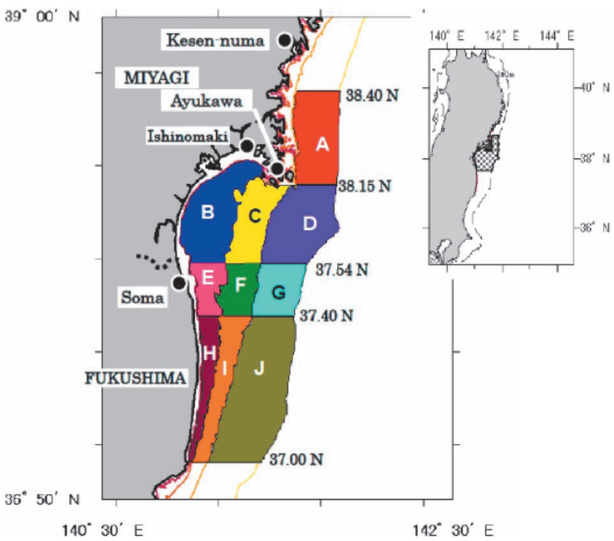

Figure 8. Ten blocks (A–J) surveyed for whales' prey species in Sanriku since 2005 (from Wada *et al.*, 2016).

Table 3

Biomasses of sand lance and Japanese anchovy in B, C, E and F blocks (surveyed in 2005 and 2006) and B, C blocks (surveyed in 2008 and 2009). See Figure 8 for surveyed blocks (from Wada *et al.*, 2016).

Year	Sandlance (tons)	Japanese anchovy (tons)
2005	7,610	1,320
2006	28,340	9,060
2008	9,310	0.2
2009	2,827	0.6

Table 4

Prey species of common minke, Bryde's and sei whales in the western North Pacific during May and September in the years 1994–2022.

Prey species/Whale species	Common minke	Sei	Bryde's
Main prey species			
Copepoda			
Neocalanus cristatus	✔	✔	
N. plumchrus		✔	
Krill			
Euphausia pacifica	✔	✔	✔
E. similis		✔	✔
E. gibboides			✔
Thysanoessa gregaria	✔	✔	✔
T. inermis	✔		
T. inspinata	✔		
T. longipes	✔		
Nematoscelis difficilis			✔
Pisces			
Japanese anchovy	✔	✔	✔
Japanese sardine	✔	✔	
Pacific saury	✔	✔	
Chub mackerel	✔	✔	✔
Spotted mackerel		✔	✔
Walleye pollocke	✔		
Japanese pomfret	✔		
Pink salmon	✔		
Chum salmon	✔		
Atka mackerel	✔		
Sand lance	✔		
Vinciguerria nimbaria			✔
Auxis rochei			✔
Squids			
Japanese common squid	✔		✔
Minimal armhook squid	✔		
Minor prey species			
Pisces			
Paralepis atlantica	✔		
Arothron firmamentum			✔
Decapterus russelli			✔
Diaphus theta			✔
Tarletonbeania taylori			✔
Starry toado			✔
Nemichthys scolopaceus			✔
Lestidiops jayakari			✔
Squids			
Japanese common squid		✔	

Summary of results for three baleen whale species

Prey species in stomach

Common minke whales (1994–2022)

A total of eighteen preys, including one species of copepod, five species of krill, ten species of fishes and two species of squids were identified in 3,036 stomachs of common minke whales (Table 4).

Sei whales (2002–2022)

A total of eleven preys, including two species of copepods, three species of krill, five species of fishes and one species squid were identified in 1,722 stomachs of sei whales (Table 4).

Bryde's whales (2000–2022)

A total of eighteen preys, including five species of krill, twelve species of fishes and one species squid were identified in 1,478 stomachs of Bryde's whales (Table 4).

Geographical and yearly changes of main prey species in the offshore area

Common minke whales (1994–2019)

Prey composition in the stomach of common minke whales is shown for each season (early [May–June] and late [July–September]), sub-area and year in Figure 9. The composition of main prey species is highly variable between years.

In sub-area 7, Japanese anchovy has been an important prey in both seasons since 1994. After 2017, Japanese sardine and mackerels have become important preys.

In sub-area 8, krill and Japanese anchovy have been important preys since 1994. After 2017, Japanese sardine has been an important prey in the early season. In late season Pacific saury has been an important prey since

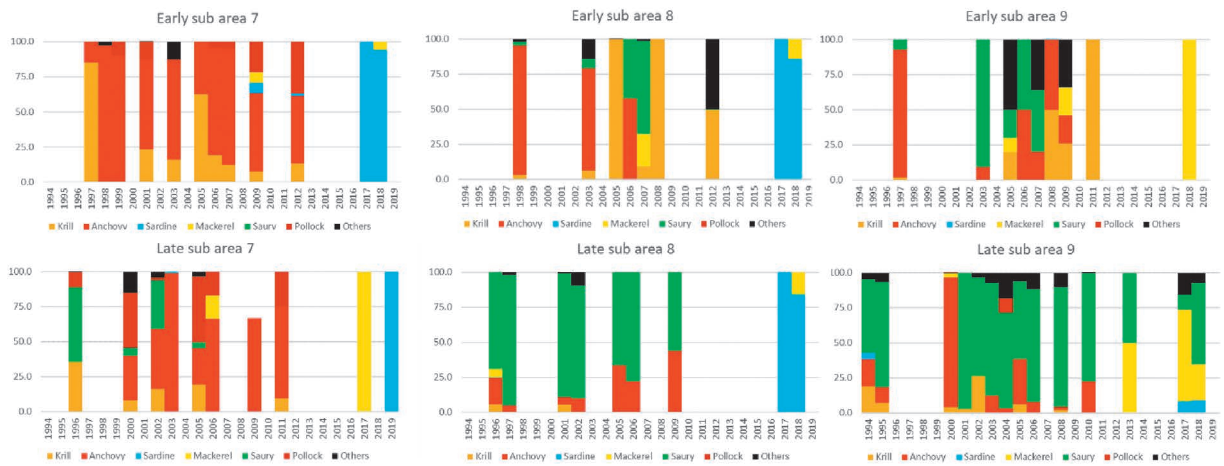

Figure 9. Prey composition in the stomach of common minke whales by season, sub-area and year, in the period 1994–2019 (partially from Konishi *et al.*, 2017).

Figure 10. Prey composition in the stomach of sei whales by season, sub-area and year, in the period 2002–2022 (partially from Konishi *et al.*, 2017).

1994. After 2017, Japanese sardine has become an important prey.

In sub-area 9, Japanese anchovy and krill have been important preys since 1994. After 2017, mackerels have become important preys in the early season. In late season, Pacific saury has been an important prey since 1994. After 2017, Pacific saury and mackerels have become important preys.

Sei whales (2002–2022)

Prey composition in the stomach of sei whales is shown for each season, sub-area and year in Figure 10. The composition of main prey species is highly variable among years.

In sub-area 7, krill and Japanese anchovy have been important preys since 2003. After 2016, Japanese sardine has become an important prey in the early season. In the late season, krill and Japanese anchovy have been important preys since 2003. After 2019, Japanese sardine and krill have become important preys.

In sub-area 8, krill, copepod, Japanese anchovy and mackerels have been important preys since 2002 in both seasons. After 2017, Japanese sardine has become an important prey.

In sub-area 9, copepod has been an important prey since 2002 in both seasons. After 2015, Japanese sardine and mackerels have become important preys.

Bryde's whales (2000–2022)

Prey composition in the stomach of Bryde's whales is shown for each season, sub-area and year in Figure 11.

In sub-area 7, krill and Japanese anchovy have been important preys since 2000. After 2020, Japanese sardine has become an important prey in the early season. In the late season, krill and Japanese anchovy have been important preys since 2000.

In sub-areas 8 and 9, krill and Japanese anchovy have been important preys since 2002 in both seasons. Occasionally, high proportions of lantern fishes were observed. After 2016, Japanese sardine has also been observed as the main prey.

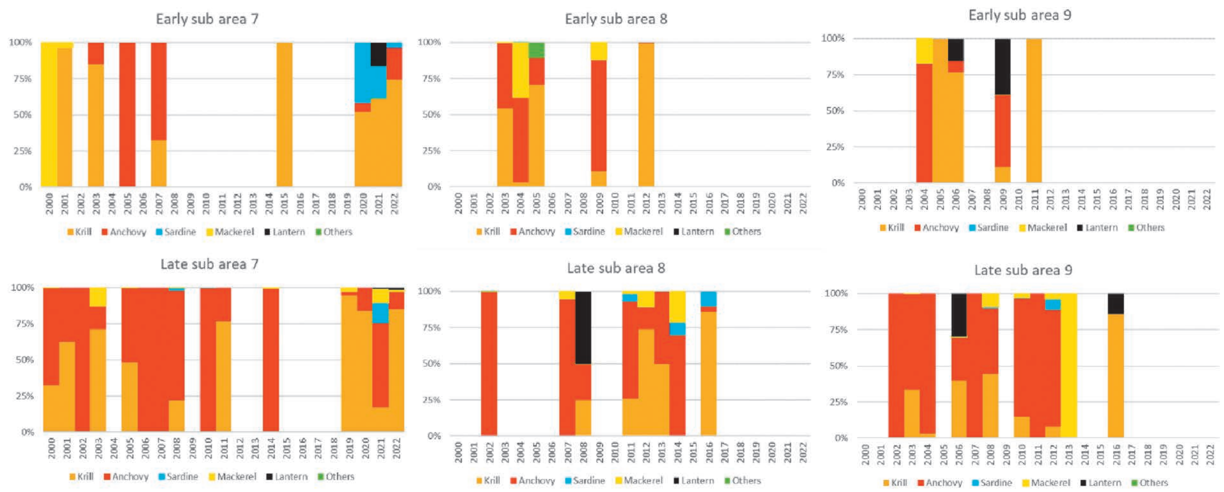

Figure 11. Prey composition in the stomach of Bryde's whales, by season, sub-area and year, in the period 2000–2022 (partially from Konishi *et al.*, 2017).

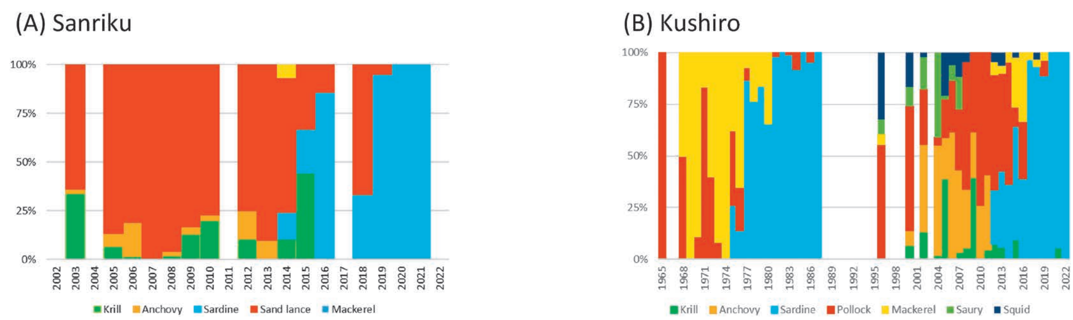

Figure 12. Yearly change of dominant prey species of common minke whales in Sanriku (A) and Kushiro (B), in the period 2002–2022 (partially from Tamura *et al.*, 2016).

Geographical and yearly changes of main prey species of common minke whales in the coastal areas (2002–2022)

Sanriku

Figure 12 shows the yearly changes in prey composition based on data from commercial whaling and some scientific surveys in Sanriku. After 2003, sand lance has been the dominant prey species. Since 2016, the dominant prey species switched from sand lance to Japanese sardine.

Kushiro

Long term information of prey composition is available from past commercial whaling (Kasamatsu and Tanaka, 1992). Figure 12 shows the yearly changes in prey composition based on data from commercial whaling and some scientific surveys in Kushiro. Until 1976, the dominant prey species of common minke whales was the chub mackerel. The dominant prey species switched from chub mackerel to Japanese sardine in 1977, from Japanese sardine to Pacific saury or Japanese anchovy in 1996, and from Pacific saury or Japanese anchovy to Japanese sardine and mackerels in 2012.

Daily and seasonal prey consumption by whales

Offshore area

The estimated daily prey consumption by sex and reproductive status is shown in Table 5 for the three species of baleen whales.

Estimated prey consumption (thousand tons) *per year* over 150 days, from May to September, in two periods (2000–2007 and 2008–2016) by three baleen whale species is shown in Table 6. See details of this calculation in Tamura *et al.* (2019). The consumption per year of Japanese anchovy by three baleen whale species in the two periods (2000–2007 and 2008–2016) were 754 thousand tons and 565 thousand ton, respectively. The consumption per year of mackerels by three baleen whale species in the same two periods was 25 thousand tons and 74 thousand tons, respectively. The consumption per year of Pacific saury by common minke and sei whales in the same two periods was 38 thousand tons and 35 thousand tons, respectively. Recently, Japanese sardine has been the dominant prey species for three baleen whale species. The consumption *per year* of Japanese sardine by three baleen whale species in the 2008–2016 period was 54 thousand tons.

Coastal areas

For Sanriku, prey consumption *per year* during mid-March to mid-June (90 days) by common minke whales is shown in Table 7. For Kushiro, seasonal prey consumption *per year* during September-October (60 days) by common

Table 5

Estimates of daily prey consumption (kg) by three baleen whale species in the offshore area, by sex and reproductive status (from Tamura *et al.*, 2019).

Species	Male		Female	
	Immature	Mature	Immature	Mature
Common minke whale	73–187	118–304	69–179	140–359
Bryde's whale	380–578	51–839	369–563	619–943
Sei whale	265–665	341–878	294–727	405–1,021

Table 6

Estimates of prey consumption (thousand tons) per year by common minke, Bryde's and sei whales in the offshore area in two different periods (from Tamura *et al.*, 2019).

Period	Prey species	Consumption (thousand tons)	Period	Prey species	Consumption (thousand tons)
2000–2007	Japanese anchovy	754	2008–2016	Japanese anchovy	565
	Pacific saury	38		Pacific saury	35
	Mackerels	25		Mackerels	74
	Japanese sardine	0		Japanese sardine	54
	Other	349		Other	593
	Total	1,166		Total	1,321

Table 7
Estimates of prey consumption (tons) by common minke whales in coastal areas of the western North Pacific based on data collected between 2002 and 2012 (from Tamura *et al.*, 2019).

Year	Sanriku				Kushiro							
	Krill	Sandlance	Anchovy	Total	Krill	Anchovy	Sardine	Saury	Mackerels	Pollock	Squid	Total
2002	—	—	—	—	453	733	0	635	0	815	1394	4,030
2003	—	—	—	—	—	—	—	—	—	—	—	—
2004	—	—	—	—	41	1,171	0	878	0	76	0	2,166
2005	1,533	2,338	606	4,477	241	170	0	20	0	1,562	101	2,094
2006	758	1,033	363	2,154	8	907	0	118	0	378	92	1,503
2007	—	—	—	—	27	292	0	125	0	227	111	782
2012	356	472	269	1,097	217	2	669	0	178	902	92	2,060
Average	882	1,281	413	2,576	165	546	112	296	30	660	298	2,106

Table 8
Prey consumption (tons) by common minke whales and fisheries catch of sand lance in Sanriku in the period 2002 and 2012. Fisheries catch data were obtained from Statistical Survey on Marine Fishery Production (https://www.maff.go.jp/j/tokei/kouhyou/kaimen_gyosei/).

Year	Prey consumption (tons)	Fisheries catch (tons)	Ratio (%)
2002	—	—	—
2003	—	—	—
2004	—	—	—
2005	2,338	8,679	26.9
2006	1,033	5,250	19.7
2007	—	—	—
2012	472	479	98.5
Average	1,281	4,803	26.7

minke whales is shown in the same table.

Amount of prey consumed by common minke whales in comparison with catch by fisheries

The estimated consumption of sand lance by common minke whales and fisheries catch of sand lance in Sanriku is shown in Table 8.

The estimated consumption of Pacific saury and walleye pollock by common minke whales and fisheries catch of those species in Kushiro is shown in Table 9. The prey consumption of Pacific saury and walleye pollock by common minke whales in Kushiro were calculated as 0–878 tons and 76–1,562 tons. Consumption of them by common minke whales in Kushiro waters corresponded to approximately 0–3% of the fisheries catch of these resources (Table 9).

To further evaluate the interaction between whale and fisheries, long-term information of prey composition of whales, accurate abundance of prey species and each whale, and accurate resident period of each whale are needed.

PROGRESS IN MODELLING WORK

This section presents an overview of the objectives and progress made in the research on ecosystem modelling in the western North Pacific. Whale abundance, prey composition and prey consumption of whales have been used as input data to the models. Those values were obtained as described above.

Offshore area

Mori *et al.* (2009) developed the EwE in the western North Pacific (north of 35°N and west of 170°E), where JARPNII surveys were conducted. The model consists of 31 species/groups ranging from detritus to whales (Table 10). Input data required for the model were biomass, production, prey consumption, diet composition and total fishery catch of each predator in the target area. When production is not available, total mortality was used in the Ecopath instead of production per biomass. Once the mass-balance model was constructed, possible effect by fisheries of the species in the model were simulated by using Ecosim under the harvesting scenarios examined.

The work by Mori *et al.* (2009) was updated in the studies by Murase *et al.* (2016b) and Watari *et al.* (2019). They have focused on the interactions between forage fish and their predators including target species of JARPNII (common minke, sei, Bryde's and sperm whales). They have updated the input data to the models by considering the data available in the period 1994–2013 and made several technical adjustments following recommendations from

Table 9
Prey consumption (tons) by common minke whales and fisheries catch of Pacific saury and walleye pollock in Kushiro in the period 2002 and 2012. Fisheries catch data were obtained from Statistical Survey on Marine Fishery Production (https://www.maff.go.jp/j/tokei/kouhyou/kaimen_gyosei/).

Prey species: Pacific saury

Year	Prey consumption (tons)	Fisheries catch (tons)	Ratio (%)
2002	635	55,594	1.1
2004	878	48,403	1.8
2005	20	58,528	0.0
2006	118	61,895	0.2
2007	125	69,629	0.2
2012	0	49,550	0.0
Average	296	57,267	0.6

Prey species: Walleys pollock

Year	Prey consumption (tons)	Fisheries catch (tons)	Ratio (%)
2002	815	52,524	1.6
2004	76	65,186	0.1
2005	1,562	54,628	2.9
2006	378	56,582	0.7
2007	227	51,088	0.4
2012	902	59,061	1.5
Average	660	56,512	1.2

Table 10
List of the species/groups used in the EwE model and Trophic Level (TL) estimated by Ecopath (from Mori *et al.*, 2009).

Species/Group	TL	Species/Group	TL	Species/Group	TL
Minke whale	3.99	Albacore	4.08	Pacific ponfret	4.20
Bryde's whale	3.83	Sword fish	4.81	Sardine	2.30
Sei whale	3.73	Skipjack tuna	3.97	Anchovy (<8 cm)	3.04
Other baleen whales	3.23	Blue shark	4.27	Anchovy (>8 cm)	3.04
Sperm whale	4.17	Samon shark	4.35	Pacific saury	3.12
Baird's beaked whale	4.15	Lantern fish	3.06	Phytoplankton	1.00
Short-finned pilot whale	4.40	Neon flying squid	4.12	Euphausiids	2.18
Ziphidae	4.24	Large surface squid	3.41	Copepods eaten by whales	2.00
Other toothed whales	4.46	Small surface squid	3.01	Other Copopods	2.00
Northern fur seal	4.08	Mid-deep water sea squid	3.11	Detritus	1.00
Marine birds	4.24	Mackerels	3.30		

the IWC Scientific Committee. They have identified several potential future data and tasks required to progress the development of ecosystem modelling in the western North Pacific.

Coastal areas

Okamura *et al.* (2009) examined the effects of predation of common minke whales on sand lance stock off Sanriku in order to investigate the effect of predation by the common minke whales in terms of MSY of sand lance population. Bayesian delay-difference model was used to develop an ecosystem model. By using new data, Kitakado *et al.* (2016) updated the model work by Okamura *et al.* (2009). The predation by the common minke whales accounts for a certain proportion of the current adult biomass of the sand lance population, although the level of proportion is sensitive to the model assumption.

The results are still preliminary because further validation of consumption of sand lance by predator species and further modelling process for linking sand lance and several predators through simultaneous estimation of populations dynamics are needed. Progress in the work on the MRM is presented in a different paper to this meeting (Kawano *et al.*, 2019).

CONCLUSIONS

The Japanese whale research programs under special permit provided important information on the ecology of several baleen whale species in the western North Pacific. Such information is key for the elucidation of the role of whales in the ecosystem. There is a need to further evaluate the interaction between prey consumption by whales and commercial fisheries, either directly or indirectly, using simulation models for specific geographical regions. The commercial whaling within Japan's Exclusive Economic Zone commenced in 2019. It is important to collect additional information on the feeding ecology of baleen whales from this source.

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