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What do we know about whales and ecosystem in the Indo-Pacific region of the Antarctic? Part 2: summary of ecological studies

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ABSTRACT

The Institute of Cetacean Research conducted whale research under special scientific permit in the Antarctic starting from the austral summer season 1987/88. The research was conducted systematically under different research programs such as JARPA and JARPAII, and more recently, under NEWREP-A. These research programs employed both lethal and non-lethal methods. NEWREP-A ceased after the 2018/19 austral summer season as a consequence of Japanʹs decision to withdraw from the International Convention for the Regulation of Whaling. Japanʹs whale research continues in the Antarctic, using non-lethal methods only. This paper summarizes the most relevant ecological outputs from Japanʹs whale research under special scientific permit in the Indo-Pacific region of the Antarctic.

INTRODUCTION

Japan conducted systematic research on whales and the Antarctic ecosystem for more than 30 years. The first research program was the Japanese Whale Research Program under Special Permit in the Antarctic (JARPA), which was followed by JARPAII and subsequently by the New Scientific Whale Research Program in the Antarctic Ocean (NEWREP-A). The Institute of Cetacean Research (ICR) was the institution in charge of designing and implementing those research programs. Tamura *et al.* (2017) have provided details on the objectives, sampling and analytical methodology of the three research programs. Several international review workshops (e.g., IWC, 2015) discussed and evaluated the large amount of data and results from these research programs.

As a consequence of Japanʹs change in whaling policy, the NEWREP-A ceased on 30 June 2019, the date of Japanʹs withdrawal from the International Convention for the Regulation of Whaling (ICRW). From the 2019/20 austral summer season, Japan started whale research in the Antarctic using non-lethal methods. The new research program is called the Japanese Abundance and Stock-structure Surveys in the Antarctic program (JASS-A) (see Isoda *et al.*, this issue).

At this point, it was considered important to summarize the knowledge on whales and the Antarctic ecosystem accumulated so far by Japanʹs whale research in the Antarctic. The objective of this paper is to summarize the most relevant ecological outputs from Japanʹs whale research under special scientific permit in the Indo-Pacific region of the Antarctic.

SURVEYS, DATA AND SAMPLES

Surveys were conducted in the Indo-Pacific region of the Antarctic, which correspond to the International Whaling Commission (IWC) Management Areas III, IV, V and VI (Figure 1). Survey and sampling methodologies of the Japanese whale research programs in the Antarctic were described in Pastene *et al.* (2014) and Tamura *et al.* (2017). A list of data and samples collected by these whale research programs in the Antarctic is available in IWC (2015).

MAIN RESEARCH OUTPUTS ON WHALE ECOLOGY

Abundance and abundance trends of baleen whales

JARPA and JARPAII conducted vessel-based sighting surveys under the Line Transect Method with the aim of estimating abundance and abundance trends of large whales in the Indo-Pacific sector of the Antarctic. Details of the methodology used are available in Tamura *et al.* (2017) and Hakamada and Matsuoka (2017). The latter authors summarized the information on abundance and abundance trend of Antarctic minke whales, which is not repeated here. Figure 2 shows pictures of the relevant baleen whale species.

Baleen whale species other than the Antarctic minke whale were depleted by unregulated commercial whaling

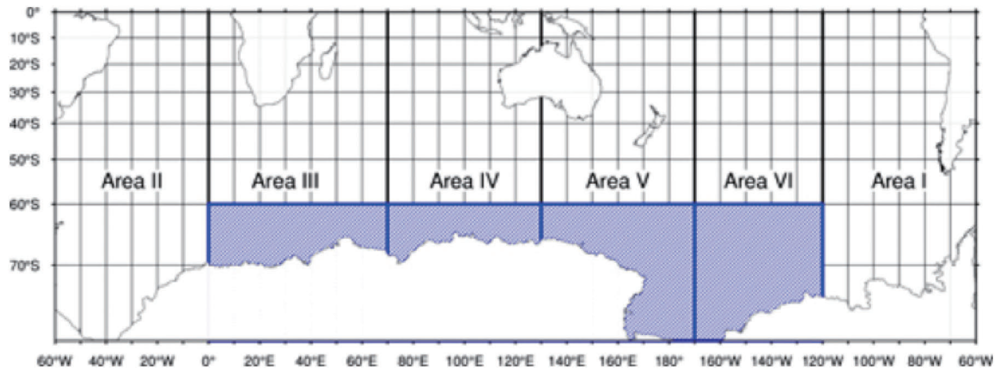

Figure 1. Research area of JARPA, JARPAII and NEWREP-A in the Indo-Pacific region of the Antarctic.

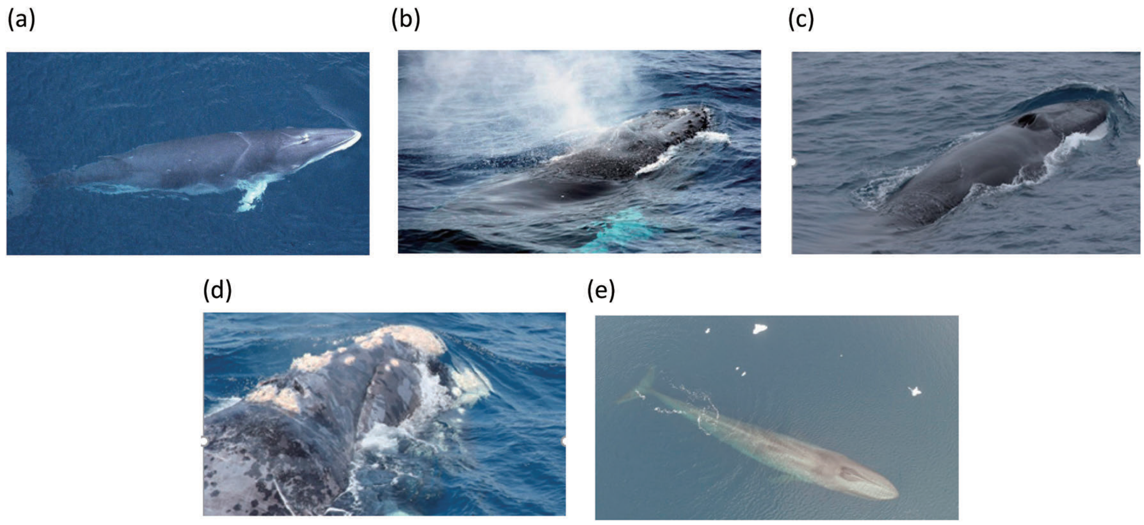

Figure 2. Baleen whale species in the Indo-Pacific region of the Antarctic: (a) Antarctic minke whale; (b) humpback whale; (c) fin whale; (d) southern right whale; (e) Antarctic blue whale.

in the past, and there is an interest to investigate the recovery of those species after protection. Fortunately, the abundance of large whale species such as humpback, fin, southern right and blue whales has been increasing, albeit at different rates over the past decades. An increase in the abundance of large baleen whales has implications for the Antarctic ecosystem as a whole (Fujise and Pastene, 2018).

The scientific evidences for the recovery of baleen whale species are shown below.

Humpback whales

Abundance and abundance trend should be ideally estimated on a biological stock basis. The IWC SC has identified seven breeding stocks of humpback whales in the Southern Hemisphere, which are denominated with alphabetic letters from ʻA′ to ʻG′ (IWC, 2011). The breeding stocks occurring in the Indo-Pacific sector of the Antarctic are Stock ʻC′ (mainly in Area III), ʻD′ (mainly in Area IV), ʻE′ (mainly in Area V), and ʻF′ (mainly in Area VI) (Kanda *et al.*, 2014). There are some geographical overlaps between adjacent stocks in the Antarctic.

Abundance and abundance trend estimates based on Japanese surveys have focused mainly on Areas IV (Breeding Stock D) and V (Breeding Stock E). In Area IV the abundance was estimated at 29,067 whales (CV=0.255) based on sighting data collected in 2007/08; in Area V the abundance was estimated at 13,894 whales (CV=0.338) based on sighting data collected in 2008/09 (Hakamada and Matsuoka, 2014a).

Figure 3 shows the abundance trend of Breeding Stocks D and E based on JARPA and JARPAII data. For comparison purposes, the figures include data from the International Decade for Cetacean Research/Southern Ocean Whale and Ecosystem Research (IDCR/SOWER) programs. The figures show a clear increasing trend which is consistent for JARPA, JARPAII and IDCR/SOWER survey data. Annual rate of increase was estimated at 13.6% (95% CI=8.4–18.7%) and 14.5% (95% CI=7.6–21.5%) for Areas IV and V, respectively. The rate of increase in Areas IV and V were statistically significant (Hakamada and Matsuoka, 2014a).

The current abundance of Breeding Stock D in Area

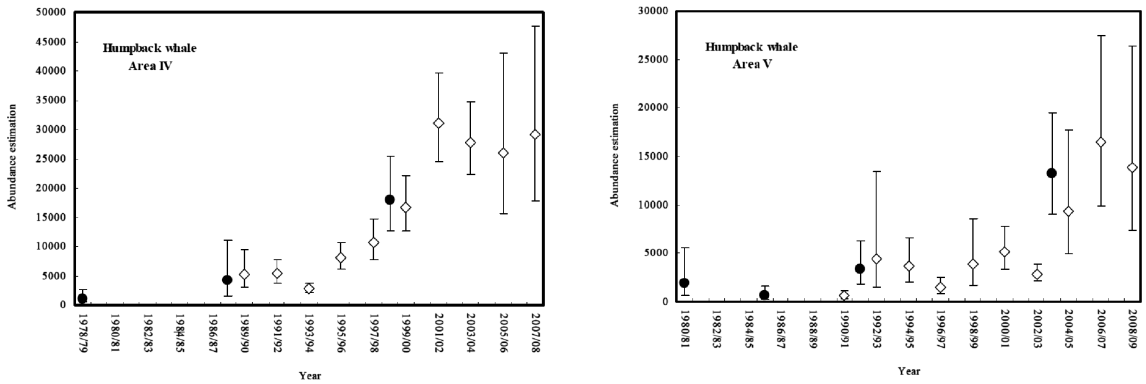

Figure 3. Abundance estimates for humpback whales in Areas IV and V (south of 60°S). Estimates were based on sighting data collected by JARPA and JARPAII between 1989/90 and 2008/09 primarily during January to February. Estimates from the IDCR-SOWER surveys (Branch, 2011) are shown for comparative purposes (filled circles). Vertical lines show 95% confidence intervals (after Hakamada and Matsuoka, 2014a).

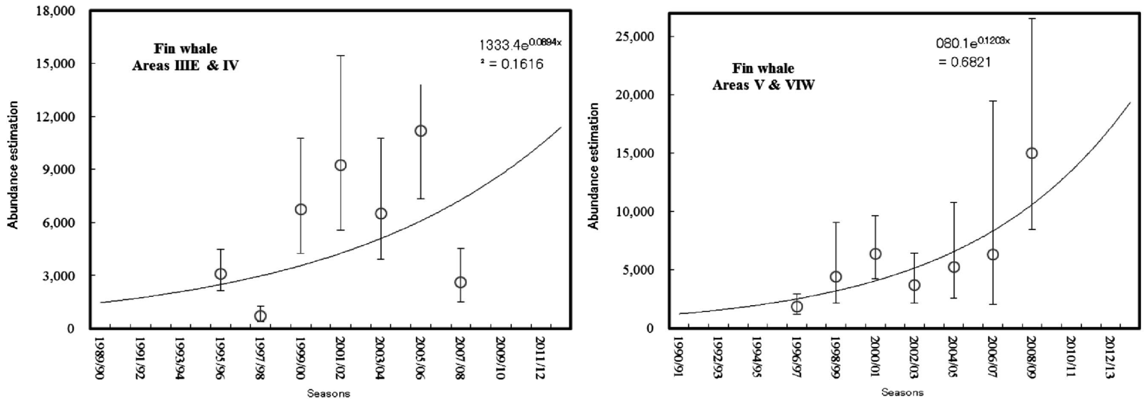

Figure 4. Abundance trend of fin whales in the Indo-Pacific region of the Antarctic, south of 60°S. Vertical lines show 95% confidence intervals (after Matsuoka and Hakamada, 2014).

IV is close to that of its pre-exploitation level (IWC HP: https://iwc.int/status).

Fin whales

There is limited information on stock structure of fin whales in the Indo-Pacific sector of the Antarctic. For the purpose of the abundance estimates based on JARPA and JARPAII surveys, the whole area was divided into western area (assuming an Indian Ocean stock in Area IIIE+IV) and eastern area (assuming a Pacific Ocean stock in Area V+VIW). Figure 4 shows the abundance estimates of fin whales in Areas IIIE+IV and V+VIW, plotted against the survey seasons. An increasing trend in abundance is evident for these two areas. For the western area the abundance south of 60°S was estimated at 3,087 (CV=0.191) in 1995/96, and 2,610 (CV=0.285) in 2007/08. For the eastern area the abundance south of 60°S was estimated at 1,879 (CV=0.226) in 1996/97, and 14,981 (CV=0.298) in 2008/09.

For the western area the increasing trend between 1995/96 and 2007/08 seasons was estimated at 8.9% (95% CI: −0.145%, 32.4%), while the trend in the eastern area between 1996/97 and 2008/09 was estimated at 12.0% (95% CI: 2.6%, 21.5%). The estimate for the eastern area was statistically significant (Matsuoka and Hakamada, 2014).

Southern right whales

During the JARPA and JARPAII surveys in Areas III–VI, this species was mainly sighted in Area IV. In this Area, abundance estimates (south of 60°S) ranged from 6 (CV=0.761) in the 2003/04 season to 1,557 (CV=0.303) in the 2007/08 season.

Figure 5 shows the abundance estimates in Area IV plotted against the survey seasons. The abundance trend was estimated at 5.9% (95% CI: −16.4%, 28.1%) between 1989/90 and 2007/08, which was not statistically significant (Matsuoka and Hakamada, 2014).

Blue whales

There is limited information on stock structure of blue whales in the Antarctic. Abundance of this species for the

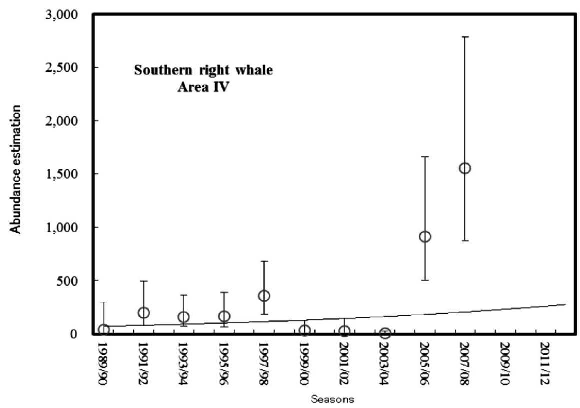

Figure 5. Abundance estimates of southern right whales in Area IV (south of 60°S). Vertical lines show 95% confidence intervals (after Matsuoka and Hakamada, 2014).

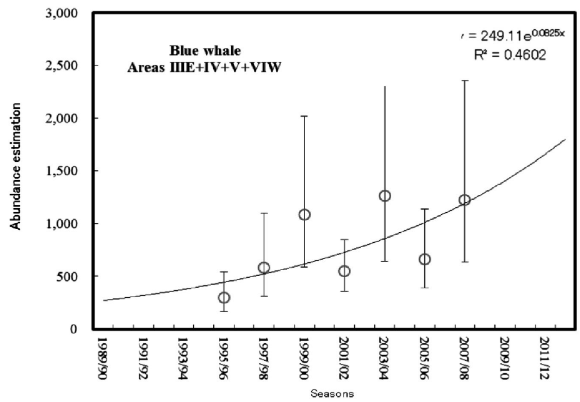

Figure 6. Abundance trend of blue whales in the Indo-Pacific region, south of 60°S. Vertical lines show 95% confidential intervals (after Matsuoka and Hakamada, 2014).

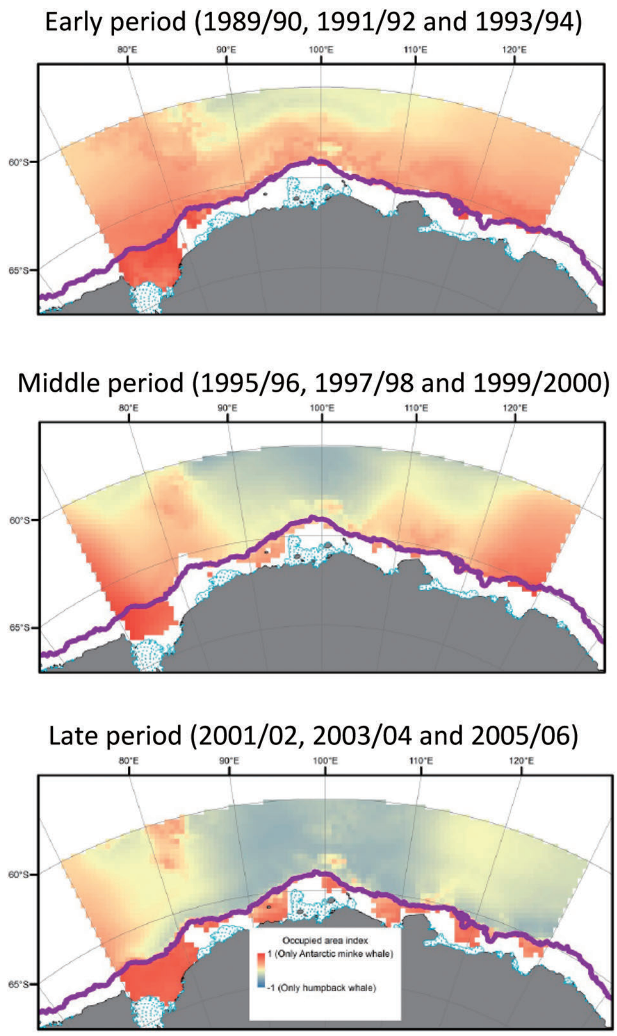

Figure 7. Occupied area indices of Antarctic minke and humpback whales in Area IV in three periods of JARPA and JARPAII (Murase *et al.*, 2014).

Indo-Pacific region of the Antarctic (35°E–145°W), south of 60°S was 664 (CV=0.328) in 2005/06 and 2006/07 seasons. The abundance was estimated at 1,223 whales (CV=0.345) in the 2007/08 and 2008/09 seasons.

Figure 6 shows the abundance estimates for the whole Indo-Pacific region plotted against the survey seasons. The abundance trend was estimated at 8.2% (95% CI: 3.9%, 12.5%) between 1995/96 and 2008/09. This estimate was not statistically significant.

Future surveys and analyses

Dedicated sighting surveys were planned for the seasons 2009/10–2013/14 under JARPAII. However, those surveys could not be conducted due to external interferences by an NGO (Nishiwaki *et al.*, 2014). Subsequently, dedicated sighting surveys were conducted under the NEWREP-A between 2015/16 and 2018/19 and data collected during these surveys are under analyses. From 2019/20 Japan started the JASS-A, which will be conducted for a tentative period of eight years. The main objective of JASS-A is to estimate the abundance of large whales in the Indo-Pacific region of the Antarctic (Government of Japan, 2019) (see Isoda *et al.*, this issue). Data collected during NEWREP-A and JASS-A will be analyzed by ICR scientists in conjunction with previous data in the same area.

Geographical distribution of baleen whales

Substantial increase in the abundance could have an implication in the pattern of distribution of the species. In the Indo sector of the Antarctic (Area IV), humpback whales have increased significantly over the past decades, while the abundance of Antarctic minke whales has been rather stable. Under this scenario, we should expect changes in the pattern of distribution of these two species.

Changes in the spatial and temporal distribution patterns of Antarctic minke and humpback whales in Area IV were examined for the period of JARPA and JARPAII. The spatial distribution was estimated using Generalized Additive Models (GAM) (Murase *et al.*, 2014). Presence or absence of whales was used as a response variable while seafloor depth, distance from shelf break and longitude were used as explanatory variables. Three time periods were defined: 'Early' (1989/90, 1991/92, 1993/94); 'Middle' (1995/96, 1997/98, 1999/00) and 'Late' (2001/02, 2003/04, 2005/06).

Figure 7 shows the results of the GAM analyses. In the early period, humpback whales were mainly distributed in the northern part of the survey area between longitudes 80°E and 100°E. In the middle period, humpback whales expanded their habitat closer to the shelf break between the longitudinal range of 80°E and 120°E. In the late period, humpback whales were distributed in the entire survey area along the shelf break. While the spatial distribution of humpback whales expanded during the period of JARPA and JARPAII, no strong change was observed in the distribution of Antarctic minke whales. These results indicated a possible competition for habitat between humpback and Antarctic minke whales as abundance of humpback whales increased.

The pattern of spatial distribution for other large whales was examined by Matsuoka and Hakamada (2018). Based on JARPA and JARPAII data, there was a common pattern for several whale species to concentrate mainly in the sector between 80°E and 110°E, south of 60°S. This could be related to krill availability, as a high density of euphausiids was reported between 100°E and 120°E in the 1999/00 JARPA survey (Murase *et al.*, 2002). Studies into the pattern of temporal (yearly) changes in relation to changes in environmental factors are underway.

Feeding ecology of Antarctic minke whale

An overview of the procedures for examining stomach content analyses by Japanese scientists was presented by Tamura and Konishi (2014). The type and amount of prey consumed by Antarctic minke whales in the feeding season is fundamental for understanding the impact of the consumption on the ecosystem. The analyses of stomach contents in Antarctic minke whales have benefited from useful suggestions and recommendations from the IWC SC.

Antarctic minke whales feed mainly on Antarctic krill (*Euphausia superba*) in offshore waters, and on ice krill (*E. crystallorophias*) (Figure 8) on the coastal shelf along the Ross Sea and Prydz Bay (Tamura and Konishi, 2009; 2014).

Figure 8. Ice krill (upper) and Antarctic krill (lower).

The maximum weight of stomach contents of Antarctic minke whales sampled by JARPA and JARPAII from 1987/88 to 2010/11 were 142.4 kg (2.4% of body weight) and 156.0 kg (3.4% of body weight) for immature males and females, respectively. The figures were 387.0 kg (3.8% of body weight) and 326.9 kg (3.6% of body weight) for mature males and females, respectively. The average weight and rate of stomach contents *per* body weight (RSC) were 33.2±28.3 kg (RSC: 0.8%) and 37.6±29.1 kg (RSC: 0.9%) for immature males and females, respectively and 63.5±47.1 kg (RSC: 0.9%) and 71.8±54.3 kg (RSC: 0.9%) for mature males and females, respectively (Tamura and Konishi, 2014).

The daily prey consumption by the whales in each reproductive status group was estimated using energy-requirement and energy deposition methods. The daily prey consumptions of Antarctic minke whales *per capita* during the feeding season based on these two methods were 95.1–127.0 and 182.6–250.3 kg for immature and mature males, 125.8–138.7 and 268.1–325.5 kg for immature and mature females, respectively. This is equivalent to 2.65–4.02% of their body weight. The total prey consumption of Antarctic minke whale *per capita* during the feeding season was 8.6–10.4 and 20.6–21.9 tons for immature and mature males, and 11.3–12.5 and 32.2–39.1 tons for immature and mature females, respectively (Tamura and Konishi, 2014).

Estimation of the uncertainties (e.g., allometric relationships, body weight of whales, energy values of prey species, assimilation efficiency and length of feeding period) in several components involved in estimating the amounts and types of prey consumed by North Pacific baleen whales was based on suggestions from the IWC SC.

Similar estimations of uncertainties are being conducted for Antarctic minke whales.

In Areas III east and IV in the 2007/2008 season, the abundance of Antarctic minke whales was estimated at 9,406 and 14,739, respectively. In Area V and VI west in the 2008/2009 season, the abundance was estimated at 108,097 and 26,364, respectively (Hakamada and Matsuoka, 2014b). These abundance estimates were used for investigating the total consumption of krill by Antarctic minke whales.

In Areas III east and IV the seasonal (120 days) prey consumption of krill by Antarctic minke whales was estimated at 0.17–0.19 and 0.33–0.37 million tons, respectively. In Areas V and VI west, the consumption was estimated at 2.51–2.88 and 0.50–0.54 million tons, respectively. The seasonal prey consumption by Antarctic minke whales in the total research area was estimated at 3.51–3.98 million tons, amounting to 7.6–8.6% of the krill biomass estimated by acoustic survey in the research area (Tamura and Konishi, 2014).

Energetics of Antarctic minke whale

Whales generally accumulate energy as lipid in the blubber during the summer feeding period at high latitudes, and they spend the energy in migration and reproduction in low latitude waters. The proxy of fat reserves in blubber have been used as an indication of body condition in whale studies (e.g., Lockyer *et al.*, 1985; 1986). The measurements of blubber thickness positively correlate with lipid content in the whole body fat and have proven to be a dependable proxy for energy storage in whales (Lockyer *et al.* 1985).

For the 18 years of JARPA period (1987/88–2004/05), the annual trend in energy storage in the Antarctic minke whales was examined using blubber thickness (Figure 9) at two lateral measurement points, in addition to total fat weight in the whale body and girth measured at two specified positions.

Blubber thickness measurements were available for 4,689 whales; fat weight was available for 740 whales; and half girth measurements were available for 4,681 animals. Regression analysis was carried out on blubber thickness in 4,689 whales. The explanatory variables were age, body weight, fetus length and total fat weight. A large number of linear mixed-effects statistical models were investigated for each of the dependent variables, and the Bayesian Information Criterion (BIC) was used to select the best model. All models examined had 'year' as a possible explanatory variable. This regression analyses clearly showed that blubber thickness had been decreasing in this period. The decrease per year in the JARPA period was estimated at approximately 0.02 cm for mid-lateral blubber thickness (Figure 10).

Similar analyses and results were found for fat weight, which decreased 17 kg in the 18-year period (Figure 10). Furthermore, the runs using 'half girth' as another dependent variable also gave similar results. The total magnitude of the decline over these 18 years was 4% for girth

Figure 9. Measurement of blubber thickness.

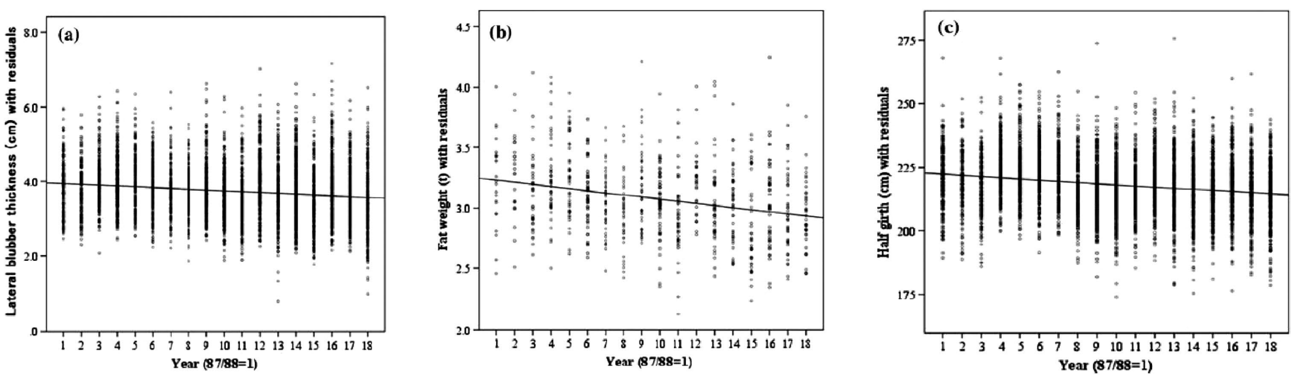

Figure 10. Temporal trends in body condition indicators of Antarctic minke whales in the feeding season (a: blubber thickness; b: fat weight; c: half girth) for the Antarctic minke whale in the feeding season (Konishi *et al.*, 2008).

measurements (Figure 10).

Similar analyses were conducted for stomach contents weight (sieved contents of the forestomach). Regression analyses using the weight of the stomach contents as the dependent variable, and explanatory variables such as year, date, local time, latitude, sex and body length, were conducted. A linear mixed-effects analysis showed a 31% (95% CI=12.6–45.3%) decrease in the weight of stomach contents over the 20 years since 1990/1991 (Konishi *et al.*, 2014).

The trend in stomach content was consistent with that of the blubber thickness (Konishi and Walløe, 2015). These results suggested that the food availability for Antarctic minke whales may have declined in recent decades.

Monitoring of environmental pollutants

Pollutant analyses by Japanese scientists started under the JARPA program for the objective of ʻElucidation of the effect of environmental changes on cetaceansʼ and continued under the JARPAII program. The objective involved the elucidation of the pattern of pollutant accumulation and the effects of pollutants on cetaceans. Different kinds of pollutants were monitored, which included trace elements and organochlorine compounds (OCs). Trace elements included the toxic ones Hg, Cd, Pb and Ni (non-essential elements), and Cu, Zn, Fe and Mn (essential elements). Toxic elements induce adverse effects in animals and humans, and are more persistent than the essential elements. Essential elements are important for survival and health of animals and humans.

Details of the analytical procedures for pollutants were given in Appendix 4 of Government of Japan (2005).

Regarding OCs, the levels of PCB and DDT in fin and Antarctic minke whales in the Antarctic Ocean could be the lowest among whale species in the world (Figure 11) (Yasunaga *et al.*, 2006). The results during the JARPA/JARPAII period suggested that levels of HCHs in the Antarctic Ocean have varied from decreasing slightly to being steady in the mid-1990s. HCB levels in large whales would be affected by trophic levels of its preys rather than by spatial differences.

Regarding trace elements, the hepatic Hg levels of Antarctic minke whales of all age groups in Area IV decreased significantly over the research years, whereas that of 15–26 years old whales in Area V increased significantly, possibly indicating that food availability of Antarctic minke whales in the 2000s may have differed from those in the 1980s and 1990s (Yasunaga *et al.*, 2014).

Oceanography

Information on oceanographic structure and its dynamics are important in interpreting changes in the Antarctic ecosystem. Changes in oceanographic conditions affect krill distribution and biomass and, in turn, the abundance and distribution of whales. Changes in oceanographic conditions might indicate an effect of climate change. Details of the oceanographic survey can be found in Wada (2019).

Watanabe *et al.* (2014) analyzed oceanographic observation data obtained by JARPA and JARPAII to clarify

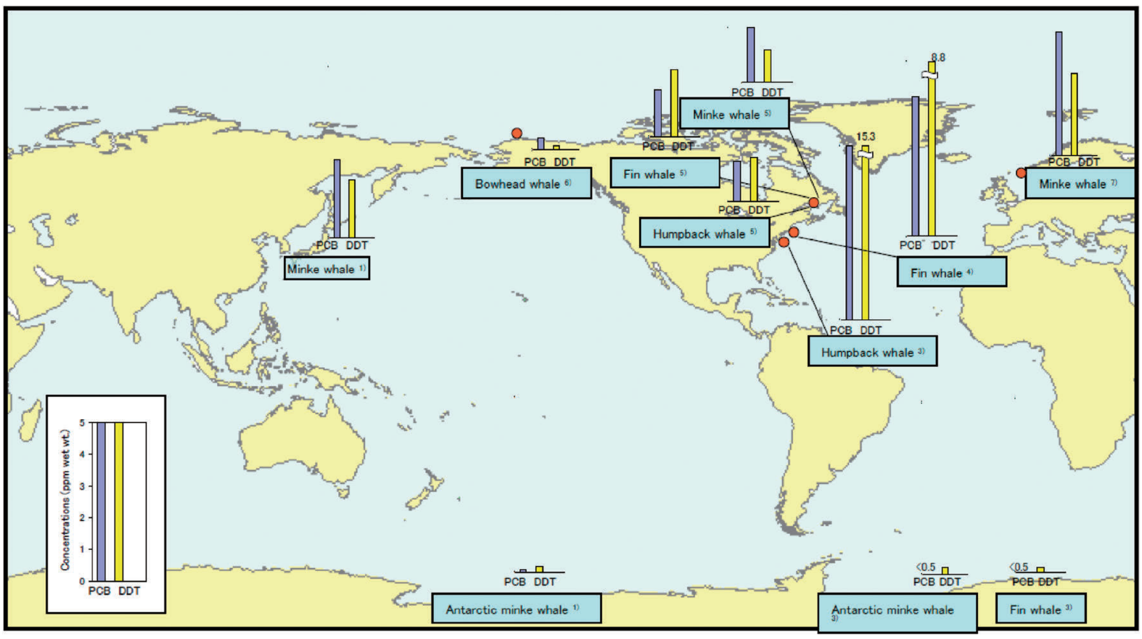

Figure 11. PCB and DDT levels in the blubber of baleen whales (Yasunaga *et al.*, 2006).

physical oceanographic conditions in the JARPA/JARPAII research area as a basis for understanding the habitat environment of whales. About 2,500 profiles were obtained by XBT, XCTD and CTD observations from 1990 to 2009. Based on this data set, the averaged feature of the oceanographic structure in the research area for two decades was described. In the area east of the Kerguelen Plateau, the position of the Southern Boundary (SB) changed on a decadal timescale. The SB is indicated by the 0°C contour on 27.6σ_0. The southward shift of the SB in the region was observed in the early 2000s, and the northward shift was observed in the later 2000s (Figure 12).

Unlike the Antarctic Peninsula region, the JARPA and JARPAII temperature data showed no statistically significant warming in the JARPA area for the two decades.

Investigation of the oceanographic conditions in the Indo-Pacific region of the Antarctic is one of the secondary objectives of JASS-A. Data will be analyzed in conjunction with the large data sets produced by JARPA/JARPAII and NEWREP-A in the Indo-Pacific region of the Antarctic.

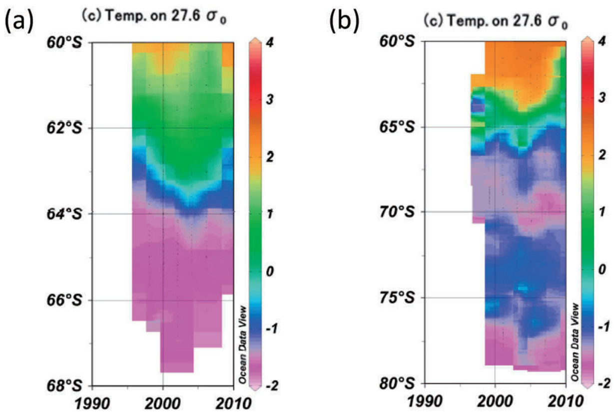

Figure 12. Temperature on the 27.6σ_0 isopycnal surface for the Area IV (a) and Area V (b) (Watanabe *et al.*, 2014).

Krill survey

Krill is a key prey species in the Antarctic ecosystem, supporting different species of baleen whales, pinnipeds, birds and fish. For this reason, the ICR has been conducting krill surveys alongside the whale sighting surveys. Sighting of whales and krill surveys were carried out concurrently in JARPAII and NEWREP-A. Details of the krill survey can be found in Wada (2019).

Wada and Tamura (2014) presented results of krill biomass estimations based on the data from a quantitative echo sounder (EK500; Simrad, Norway). Estimations were made based on data obtained in Area IV in the 2007/08 JARPAII survey and in Area V in the 2008/09 JARPAII survey. The biomass estimates obtained in Area IV was 12.5 million tons, and that in Area V was 24.0 million tons. These estimations were useful to evaluate the impact of the krill consumption by three baleen whale species.

Regarding krill demography, information on length frequency distribution and maturity stage of Antarctic krill are being obtained using samples from stomachs of Antarctic minke whales taken in JARPA, JARPAII and NEWREP-A (1989/90–2017/18). Figure 13 shows an example of outputs of such analyses.

Marine debris

In recent years marine debris has been recorded in the sub-Antarctic and Antarctic islands. Marine debris causes negative effects on whales through ingestion and by entanglement. JARPA, JARPAII and NEWREP-A conducted systematic monitoring of marine debris in whales and their environment in the Antarctic. Details of the results of marine debris during JARPA/JARPAII can be found in Isoda *et al.* (2018).

The density index (DI: number of marine debris per 100 nautical miles) of marine debris in the Antarctic is lower by two orders of magnitude in comparison to the North Pacific Ocean and its adjacent waters. Thus, the observa-

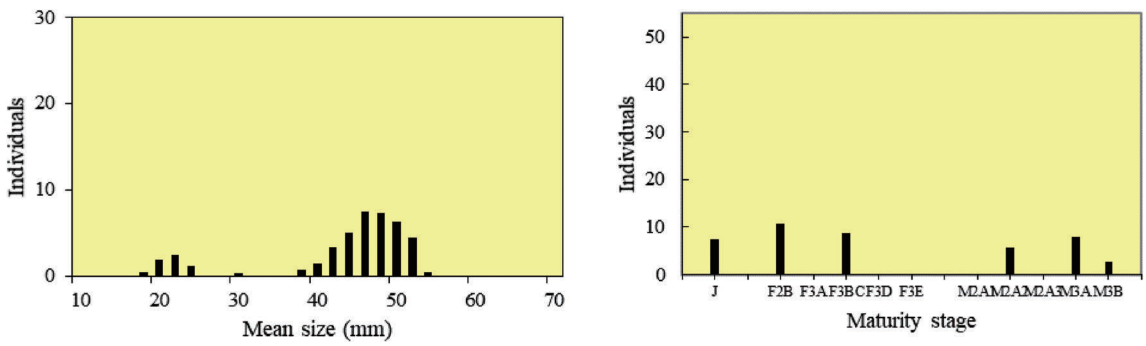

Figure 13. Length frequency distribution (left) and maturity stage (right) of Antarctic krill sampled from stomach contents of Antarctic minke whales in 2008/09 in the sector 130°E and 140°E.

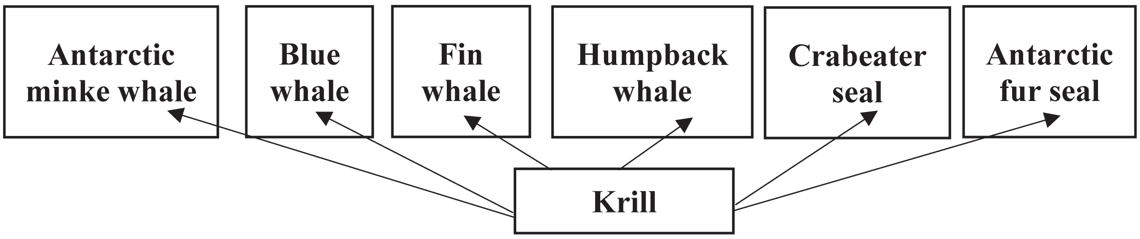

Figure 14. Food web in the Antarctic modeled in Mori and Butterworth (2006) and Moosa (2017).

tions proved that the Antarctic waters have a very low density of marine debris on the sea surface. The level of impact of entanglements on Antarctic minke whales was low in comparison with other oceanic basins. Given the low indices, the effect of marine debris on whales in the Antarctic was expected to be limited at the present time (Isoda *et al.*, 2018).

Modelling work

An overview of the ICR work on ecosystem modelling in the Antarctic was presented by Hakamada and Tamura (2018). The ecological background for the modelling exercise was provided by Fujise and Pastene (2018).

Mori and Butterworth (2006) constructed a multi-species modelling in the Antarctic Ocean using baleen whales and seals as predators and krill as prey (Figure 14). One of the main objectives of their modelling exercise was to determine whether predator-prey interactions alone can broadly explain observed population trends without the need for recourse to environmental change hypotheses. Preliminary results indicated that this is likely to be the case.

New ecosystem modelling studies are underway (Moosa, 2017).

CONCLUSIONS

Japan's whale research programs under special permit have provided important information on the ecology of Antarctic minke whales and other baleen whale species in the Indo-Pacific region of the Antarctic. The long time series of data produced by the research programs have been fundamental to the study and understanding of abundance trends of several large whale species, the changes in distribution of Antarctic minke and humpback whales, and the changes in nutritional conditions of the Antarctic minke whales. The research programs have produced new information in helping to understand the oceanographic structure of the Indo-Pacific region of the Antarctic.

Also, studies on the distribution, abundance and demography of the krill have commenced. Further, these programs have provided information on the level of pollutant and marine debris in the Antarctic, which fortunately are at low levels. Ecosystem models are being developed to understand the predator-prey interaction.

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