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What do we know about whales and the ecosystem in the Indo-Pacific region of the Antarctic? Part 1: Summary of results on assessment and management of Antarctic minke whales

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ABSTRACT

The Institute of Cetacean Research has conducted whale research under special scientific permit in the Antarctic since the austral summer season of 1987/88. The research was conducted systematically under different research programs such as JARPA and JARPAII, and more recently, under the NEWREP-A. These research programs employed both lethal and non-lethal methods. NEWREP-A ceased after the 2018/19 austral summer season as an effect of Japan's decision to withdraw from the International Whaling Commission and start commercial whaling within its Exclusive Economic Zone. This paper summarizes the most relevant outputs from the Japanese research programs under special scientific permit in the Indo-Pacific region of the Antarctic related to the assessment and management of Antarctic minke whales.

INTRODUCTION

Japan conducted systematic research on whales and the Antarctic ecosystem for more than 30 years. The first research program was the Japanese 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) has been 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 three research programs. Several international review workshops (e.g. IWC, 2015) discussed and evaluated the large amount of data and results from those research programs.

As an effect of the change in the whaling policy of the Government of Japan, NEWREP-A ceased from 1 July 2019. From now on, Japan will conduct whale research in the Antarctic based solely on non-lethal methods. At this point, it was considered important to summarize the knowledge on whales and the Antarctic ecosystem accumulated so far by the Japanese whale research in the Antarctic.

The objective of this paper was to summarize the most relevant outputs from the Japanese research programs under special scientific permit in the Indo-Pacific region of the Antarctic related to the assessment and management of Antarctic minke whales.

SURVEYS, DATA AND SAMPLES

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

The most relevant research outputs for assessment and management (i.e. taxonomy/stock structure, abundance and biological parameters) of Antarctic minke whales are presented in the next section.

MAIN RESEARCH OUTPUTS

Taxonomical aspects

Until relatively recently, only one species of minke whale was thought to exist: *Balaenoptera acutorostrata* Lacèpéde, 1804. However, Rice (1998) reviewed morphological (e.g. Williamson, 1959; van Utrecht and van der Spoel, 1962; Kasuya and Ichihara, 1965; Omura, 1975;

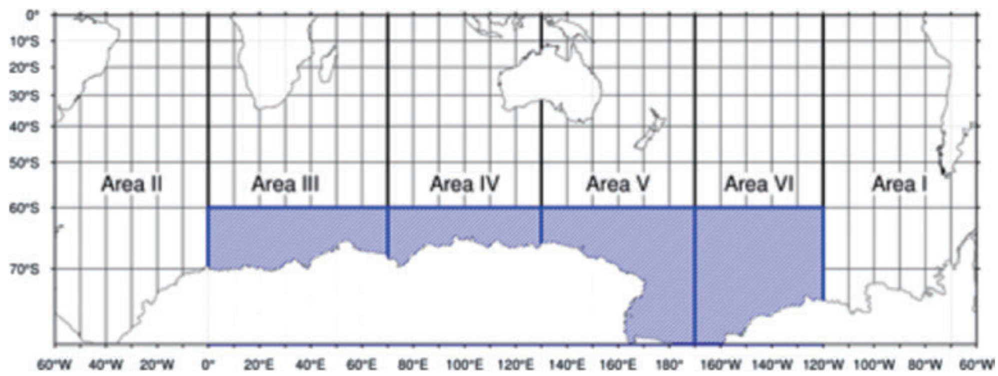

Figure 1. Research area of the JARPA, JARPAII and NEWREP-A in the Indo-Pacific region of the Antarctic.

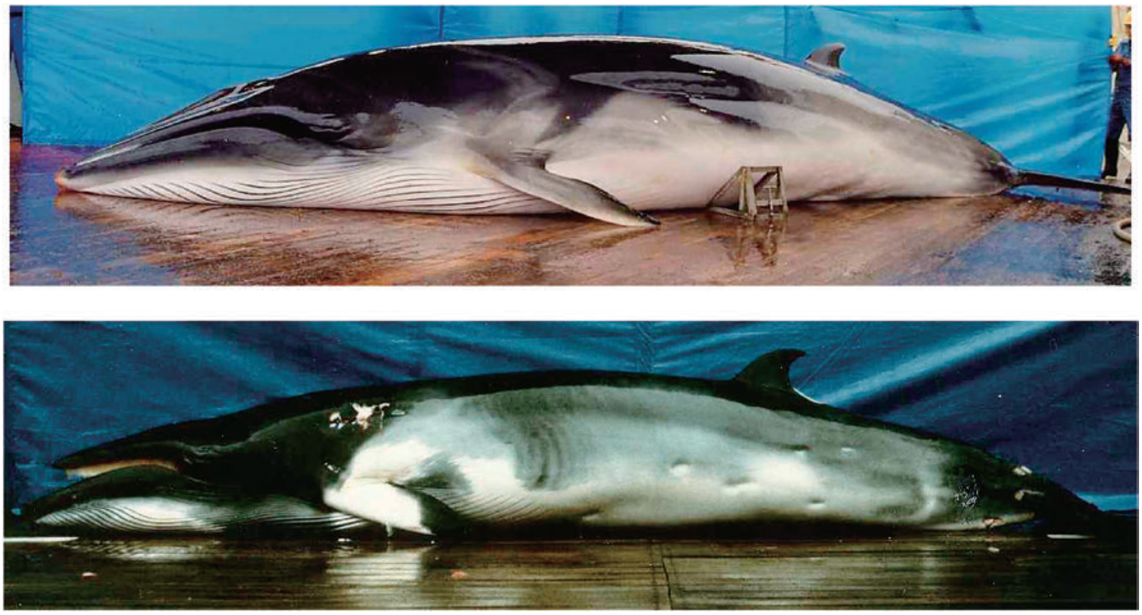

Figure 2. External appearance of Antarctic minke (above) and dwarf minke (below) whales.

Best, 1985) and genetic (e.g. Wada *et al.*, 1991; Arnason *et al.*, 1993; Pastene *et al.*, 1994) data collected from extant minke whale populations and re-specified two species, the Antarctic minke whale *B. bonaerensis* Burmeister, 1867, which is restricted to the Southern Hemisphere, and the common minke whale *B. acutorostrata* Lacèpéde, 1804, which is distributed globally.

In the Southern Hemisphere the common minke whale is known as ʻdiminutiveʼ or ʻdwarfʼ minke whale (Best, 1985; Arnold *et al.*, 1987). Currently, the dwarf minke whale is considered an un-named sub-species of *B. acutorostrata*. A large amount of biological and genetic information was obtained from 16 dwarf minke whales caught by earlier JARPA surveys in the Indo-Pacific region of the Antarctic. Earlier genetic analyses based on those samples and mitochondrial DNA (mtDNA) showed that dwarf and North Pacific minke whales were more similar to each other than they were to the Antarctic minke whale (Wada *et al.*, 1991; Pastene *et al.*, 1994).

Kato and Fujise (2000) reported on the morphology, growth and life history of dwarf minke whales based on 16 animals sampled by JARPA in the Indo-Pacific region of the Antarctic. Results of their analyses confirmed several of the morphological and morphometric characters reported previously, and the striking differences with the Antarctic minke whale. The mean body length at physical maturity was estimated at 7.0 m and 6.6 m for females and males, respectively. The age and length at sexual maturity in females was 7–10 years and 6.0–6.5 m, respectively. Furthermore, the authors stated that the conception of the dwarf minke whale is highly concentrated in mid-winter. Some additional morphological and morphometric analyses of minke whales worldwide, including dwarf minke whales, were conducted by Nakamura *et al.* (2014) and Kato *et al.* (2015).

On the basis of the morphological differences documented by Best (1985) and Arnold *et al.* (1987) and genetic differences (Wada *et al.*, 1991) the IWC Scientific Committee (IWC SC) recognized the existence of two southern minke whales and agreed that the two minke whales in the Southern Hemisphere should definitively be considered separately for management purposes (IWC, 1991). In 1993, after examining the genetic information provided by Pastene *et al.* (1994), the IWC SC recommended the inclusion of the dwarf minke whale in the *Schedule*, so that catch limits for Antarctic minke whales recognise the distinction between the two southern minke whales (IWC, 1994).

In 2000, the IWC SC again recognised the two species but deferred a decision on other nominal taxa until the completion of a worldwide review of genetic and non-genetics information for minke whales (IWC, 2001). Subsequent worldwide genetic analyses of minke whales provided further evidence for the separation of the two species, *B. bonaerensis* and *B. acutorostrata*, and at least three sub-species of the common minke whale as recognized by Rice (1998) using mtDNA sequences (Pastene *et al.*, 2010) and microsatellite DNA (Glover *et al.*, 2013).

While additional genetic and morphological/morphometric studies are required to further elucidate the taxonomic status within *B. acutorostrata*, including that of the dwarf minke whale, there is agreement on the taxonomic status of *B. bonaerensis*. Figure 2 shows the external morphological appearance of Antarctic minke and dwarf minke whales.

Stock structure of the Antarctic minke whale

Detailed information on stock structure of the Antarctic minke whale was provided by Taguchi *et al.* (2017). The main findings are summarized here.

The primary data sources for studies of stock structure in this species were from the JARPA and JARPAII programmes, both of which had stock identity as one of their objectives. Studies based upon these samples have proved to be more useful than those from the commercial period, given the wider geographical coverage and the more random sampling design. In contrast, the commercial whaling samples were taken mainly from areas of high density near the ice-edge (Pastene, 2006). Initially, the JARPA genetic studies on stock structure were based on mtDNA Restriction Fragment Length Polymorphism (RFLP), and considerable genetic heterogeneity in Areas IV and V was found (Pastene *et al.*, 1993; 1996).

Consideration of a suite of information from mtDNA and microsatellite DNA (Pastene *et al.*, 2006), morphometrics for 10 external measurements (Fujise, 1995; Hakamada, 2006) and mean length at physical maturity (Bando *et al.*, 2006) led to the conclusion that Antarctic minke whales in the feeding grounds between Areas IIIE and VIW do not comprise a single stock (IWC, 2008). Rather, the results are consistent with the occurrence of at least two genetic stocks in these feeding grounds, which are probably related to the two proposed breeding areas in the eastern Indian Ocean and western South Pacific (Kasamatsu *et al.*, 1995). The following names have been proposed for these stocks: Eastern Indian Ocean Stock (I-Stock) and Western South Pacific Ocean Stock (P-Stock) (Pastene, 2006). The analyses of the JARPA data also suggested an area of transition in the region around 150°–165°E, across which there is an as yet undetermined level and range of mixing (IWC, 2008).

Given additional data from JARPAII, the analyses of stock structure were refined in two ways: the first involved additional laboratory work for additional genetic markers, and the second involved modified analytical measures. All the Antarctic minke whales taken by JARPAII between 2005/06 and 2010/11 were sequenced for a 340 bp-segment of the control region of the mtDNA (instead of the mtDNA RFLP used in JARPA), and genotyped using 12 microsatellite loci (instead of the six used in JARPA). Results of the heterogeneity test for both markers showed statistically significant genetic differences between whales in the two sectors, western (35°–130°E) and eastern (165°E–145°W), confirming that different stocks inhabit the Indian and Pacific sectors of the Antarctic (the I- and P-stocks). Microsatellite DNA analyses showed more dispersal amongst males than females and some degree of annual variation (Pastene and Goto, 2016).

Schweder *et al.* (2011) developed an integrated approach for estimating longitudinal segregation of two stocks using various sources of data: morphometric, microsatellite and mtDNA data. This approach revealed that the soft boundary (or transition area) suggested previously could vary by year and sex. A joint likelihood function was defined to estimate mixing proportions and apply statistical tests without assuming any baseline populations. The approach was originally applied to the JARPA data (Schweder *et al.*, 2011) and subsequently to JARPA and JARPAII data (Kitakado *et al.*, 2014). The results of this approach confirmed the occurrence of at least two stocks (I and P) in the Indo Pacific sector of the Antarctic. Furthermore, the results indicated that the spatial distribution of the two stocks had soft boundaries in Area IVE (100°–130°E) and VW (130°–165°E), which changes by year. Results also suggested possible sex differences in the pattern of distribution of the two stocks (Kitakado *et al.*, 2014).

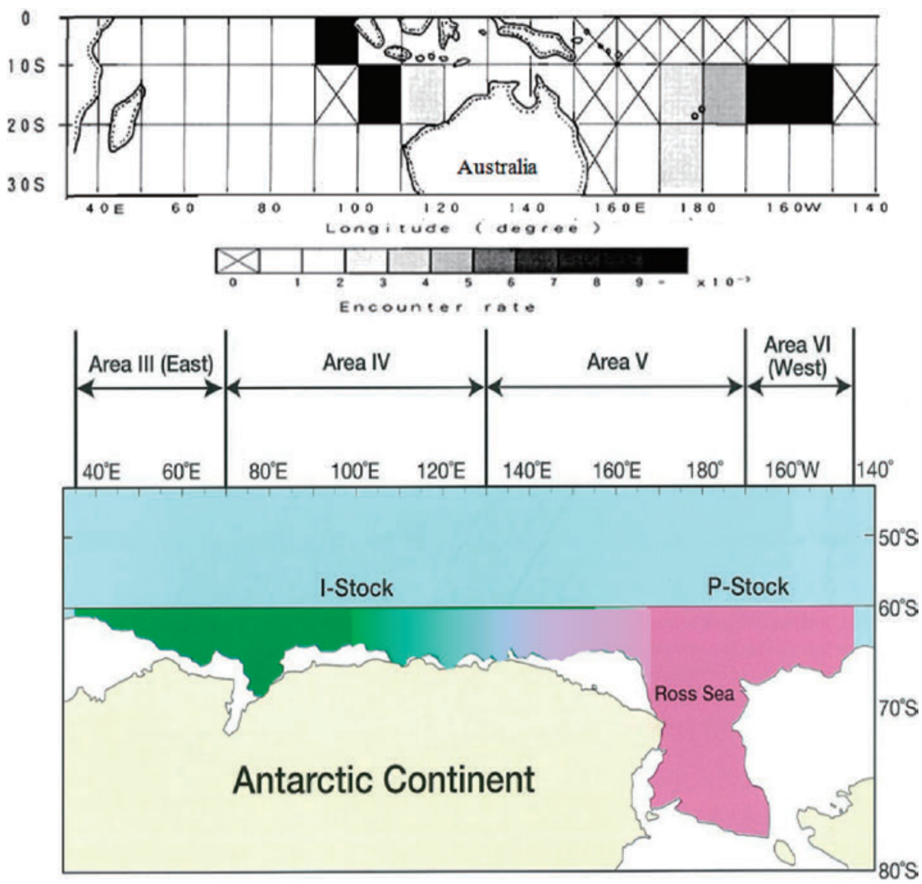

Figure 3. Hypothesis on stock structure of the Antarctic minke whale. The upper figure shows the encounter rates of Antarctic minke whales in 10° squares of latitude and longitude in waters 0°–30°S during October (Kasamatsu *et al.*, 1995). The high sighting densities in the eastern Indian Ocean and western South Pacific could correspond to breeding grounds of this species. At least two stocks (I- and P-stocks) occur in the research area of JARPA and JARPAII, which mix through a transition area. The transition area and the mixing rate appears to change by year and sex (Pastene and Goto, 2016).

Consequently, the structure of Antarctic minke whale in Areas IIIE to VIW appears to be more complex than originally thought. In summary, the IWC SC agreed (IWC, 2008) that there are (at least) two stocks with a wide mixing area that may change by year and sex. The extent of the I-stock to the west of 35°E and that of P-stock to the east of 145°W cannot be investigated due to a lack of appropriate samples.

The identification of spatial and temporal boundaries of stocks has been important for the interpretation of the biological parameters estimated of this species in the Antarctic (i.e. Punt *et al.*, 2014; Bando, 2017), and should also be important for the interpretation of abundance and abundance trends in the near future.

Figure 3 shows a schematic representation of the stock structure hypothesis derived from different analyses based on JARPA and JARPAII data.

Abundance of Antarctic minke whales

Detailed information on abundance estimates of Antarctic minke whales was provided by Hakamada and Matsuoka (2017). The main findings are summarized here.

Hakamada *et al.* (2013) estimated abundance and abundance trends of Antarctic minke whales in the Indian sector (Area IV) and Pacific sector (Area V) based on Japanese dedicated sighting surveys (JARPA and JARPAII), under the assumption of $g(0)=1$. Abundance estimates for the Indian sector range from 16,562 (CV=0.542) in 1997/98 to 44,945 (CV=0.338) in 1999/00, while those for the Pacific sector range from 74,144 (CV=0.329) in 2004/05 to 151,828 (CV=0.322) in 2002/03. Estimates of the annual rates of increase in abundance are 1.8% with a 95% CI of [−2.5%, 6.0%] for the Indian sector and 1.9% with a 95% CI of [−3.0%, 6.9%] for the Pacific sector.

Adjustments to allow for the $g(0)$ being less than 1 were made by the application of a regression model, developed from the results of the Okamura–Kitakado (OK) method estimate of minke whale abundance from the IDCR/SOWER surveys, which provides estimates of $g(0)$ from the statistics of the minke whale school size distribution in a stratum. With this adjustment, abundance estimates increased by an average of 32,333 (106%) for the Indian sector and 89,245 (86%) for the Pacific sector, while the estimates of annual rates of increase and their 95% CIs changed slightly to 2.6% [−1.5%, 6.9%] for the Indian sector and 1.6% [−3.4%, 6.7%] for the Pacific sector. See Figure 4 for the abundance trends in the two sectors.

In 2012 the IWC SC agreed to a new best abundance estimate for Antarctic minke whales in Antarctic open waters south of 60°S, based on IDCR/SOWER sighting data. The estimates were 720,000 based on the sighting data collected during the CPII (1985/86–1990/91) with 95% CI (512,000, 1,012,000), and 515,000 based on the sighting data collected during the CPIII (1992/93–2003/04) with 95% CI (361,000, 733,000). No significant statistical differences were found between the CPII and CPIII estimates (IWC, 2013).

The estimates in the Indian sector (Area IV) were 55,237 (CV: 0.17) in CPII and 59,677 (CV: 0.34) in CPIII. In the Pacific sector (Area V) were 300,214 (CV: 0.13) in CPII and 183,915 (CV: 0.11) in CPIII.

By considering the 95% CIs of the estimates it can be suggested that the stocks of Antarctic minke whales are broadly stable with at most a slight decline, therefore the conclusion on trends is similar to that derived from JARPA and JARPAII data in Areas IV and V.

Abundance of Antarctic minke whales should be interpreted in the near future in the context of additional information on stock structure of the species in the Indo-Pacific region of the Antarctic.

Biological parameters of Antarctic minke whale

Detailed information on biological parameter estimates of Antarctic minkes whale was provided by Bando (2017). The main findings are summarized here.

Estimates of biological parameters of Antarctic minke whales based on samples obtained during the JARPA, are summarized in Table 1 (IWC, 2008; Bando, 2017).

The grouping of samples for the estimates of biological parameters considered the information on stock structure summarized above.

Age dependent natural mortality was estimated from the Statistical Catch-at-Age (SCAA) model. The pattern was similar for the I and P stocks with natural mortality being higher in young and old animals. It was calculated as 0.048 (for age=15) to 0.107 (for age=35) for the I-

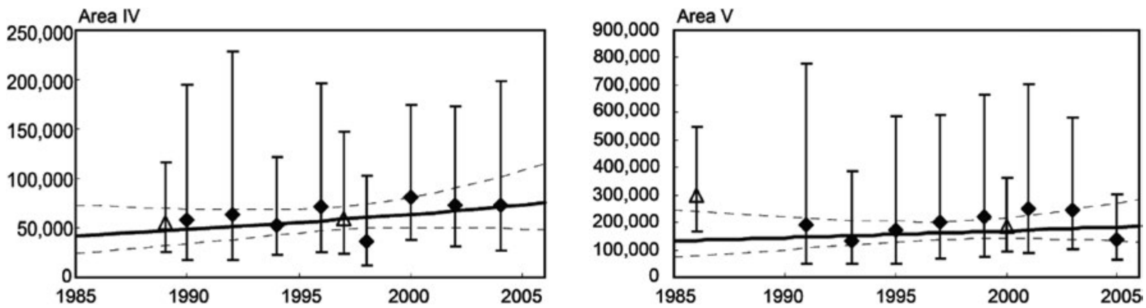

Figure 4. The best-case estimates of annual abundance of Antarctic minke whale in the Indian sector (Area IV) and Pacific sector (Area V) together with their 95% CIs. The IDCR/SOWER estimates for a common northern boundary for CPII and CPIII are shown by the open triangles. Confidence intervals include allowance for additional variance. The dashed curves indicate the 95% CIs for the exponential model (after Hakamada *et al.*, 2013).

Table 1

Summary of biological parameters of Antarctic minke whales estimated according to one stock structure hypothesis (after IWC, 2008).

		I-stock (Area IIIE+IV+VW)		P-stock (Area VE+VIW)	
		Male	Female	Male	Female
Length at sexual maturity (m)	*Lmov*		8.40m		8.30m
	Lm50%	7.29m	8.16m	7.17m	7.97m
Age at sexual maturity	*tmov*		7.9		8.4
	tm50%	5.3	7.6	5.4	8.0
Length at physical maturity (m)	50%mature	8.32m	9.12m	8.22m	8.73m
Age at physical maturity	50%mature	16.0	21.2	17.0	20.6
Growth curve		$y = 8.61(1-e^{-(0.27x+0.54)})$	$y = 9.16(1-e^{-(0.23x+0.49)})$	$y = 8.45(1-e^{-(0.29x+0.51)})$	$y = 8.93(1-e^{-(0.21x+0.59)})$
Percentage of matured females pregnant			92.9%		85.4%
Foetal sex ratio (male %)			51.8%		46.8%
Mean litter size			1.007		1.013

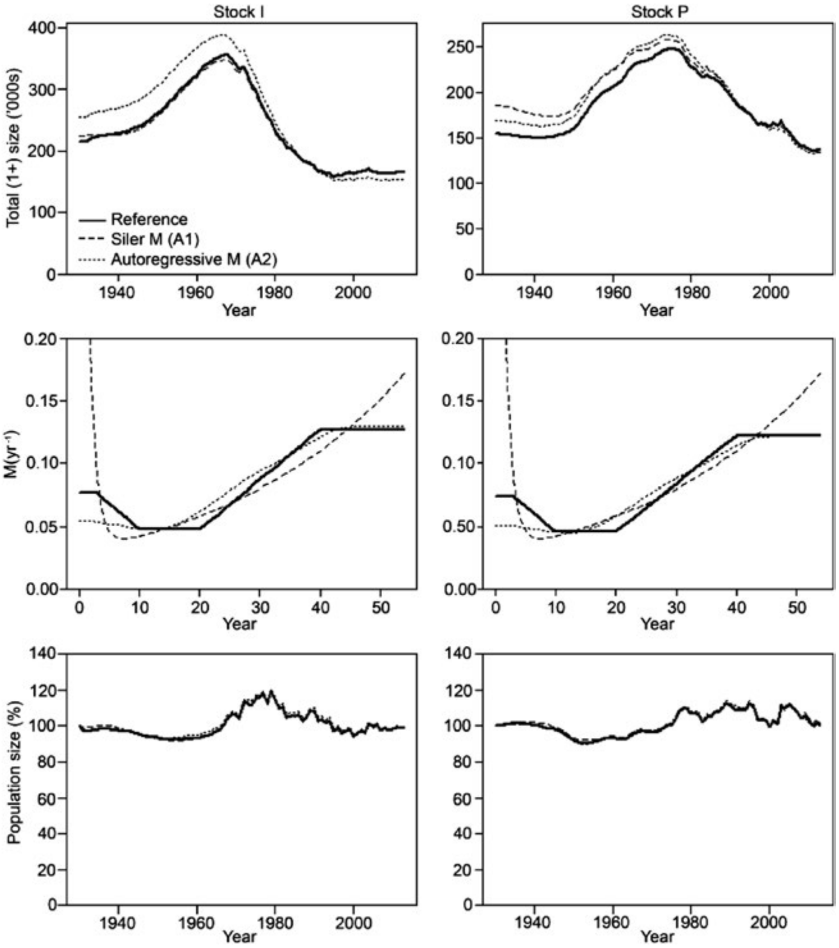

Figure 5. Time-trajectories of total (1+) population size (upper panels), age-specific natural mortality (center panels), and total (1+) population size relative to carrying capacity (lower panels) for three ways to model natural mortality (the Siler model, autoregressive and piecewise linear) of two stocks of Antarctic minke whale (from Punt *et al.*, 2014). Biological data obtained from both JARPA and JARPAII were used in the SCAA.

stock and 0.046 (for age=15) to 0.103 (for age=35) for P-stock (Figure 5) (Punt *et al.*, 2014). Time-trajectories derived from SCAA showed that total population size of the Antarctic minke whale increased until 1970′s and then declined until 2000′s for both stocks (Figure 5) (Punt *et al.*, 2014).

CONCLUSIONS

The Japanese whale research programs under special permit have provided important information on stock structure, biological parameters and abundance of Antarctic minke whales in the Indo-Pacific region of the Antarctic. Such information is key for the assessment of the species and the application of management procedures such as the IWC′s Revised Management Procedure (RMP) in the future. Continuation of the systematic monitoring of the stocks of Antarctic minke whales is recommended.

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