Observer experience and Antarctic minke whale sighting ability in IWC/IDCR-SOWER surveys

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ABSTRACT

The relationship between observer experience and the number of minke whale schools sighted on International Whaling Commission/International Decade of Cetacean Research-Southern Ocean Whale and Ecosystem Research (IWC/IDCR-SOWER) surveys from 1993/94 to 1998/99 is investigated for Independent Observer (IO) mode survey. Observer experience is defined as the number of past sightings surveys in which the observer participated. During the third circumpolar set of surveys (from 1991/92 onwards), about half of the observers had participated in fewer than five previous sightings surveys. Based upon the QAIC model selection criterion, the observers are classified into two groups depending on their experience: 'Beginners' (0-4 surveys) and 'Experts' (>4). The sighting rate for minke whale schools by Beginners is estimated to be 42% lower than that by Expert observers. Furthermore, perpendicular distances to the sightings do not show significant differences in relation to observer experience. These results jointly indicate that the probability of detection on the trackline, $g(0)$, may be less than one when Beginners are amongst those observing. Abundance estimation for minke whales in IO mode involves the sightings made by triple observer combinations, with two observers in the barrel and one observer in the Independent Observer Platform (IOP) all searching simultaneously. Surprisingly, given the result above, no significant trend in sighting rate with the combined experience of this three-observer combination is detected. This might be an artifact of small sample size for some observer combinations, such as Experts in all platforms. When observer combinations in the barrel are pooled across, the estimated trend in the sighting rate with combined observer experience becomes steeper. Furthermore, when like-minke sightings are also taken into account, the trend becomes steeper still. In this case, when observations are pooled across observer combinations in the barrel, a model for sighting rate that includes an observer effect is selected in terms of the QAIC criteria. These analyses thus provide suggestive evidence that the introduction of Beginner observers during the third circumpolar set of surveys may have reduced $g(0)$ and hence negatively biased abundance estimates for minke whales, both in absolute terms and compared with estimates from the second circumpolar set of surveys.

KEYWORDS: ANTARCTIC MINKE WHALE; TREND; G(0); SURVEYS-VESSEL; SOUTHERN HEMISPHERE; SIGHTINGS SURVEYS; ABUNDANCE ESTIMATES; METHODOLOGY

INTRODUCTION

The objective is to investigate the relationship between topman observer experience and the number of Antarctic minke whale (*Balaenoptera bonaerensis*) schools sighted during recent International Whaling Commission/ International Decade of Cetacean Research-Southern Ocean Whale and Ecosystem Research (IWC/IDCR-SOWER) surveys. Observer experience is defined as the number of times the observer participated in previous whale sightings surveys (IWC/IDCR-SOWER or other similar surveys). As shown in Fig. 1, the experience of the primary observers (both topmen and the Captains) in IWC/IDCR-SOWER surveys has generally declined since 1992/93 (Matsuoka *et al.*, 2001). During the second circumpolar set of surveys (1984/85-1990/91), all topman observers had participated in at least ten previous sighting surveys. However, during the third circumpolar set of surveys (1991/92 onwards), typically half of these observers had participated in no more than four such surveys.

Fig. 2 shows the trend of the number of Antarctic minke whales estimated from the IWC/IDCR-SOWER surveys by Branch and Butterworth (2001), whose analyses assumed $g(0) = 1$. The estimated number of Antarctic minke whales during the third circumpolar set of surveys, especially from 1992/93 which is the year the observers who had less experience started to participate, has been low compared to the earlier surveys (even after allowing for the fact that these later surveys covered lesser longitudinal ranges). This paper investigates whether there is a relationship between topman observer experience and the number of schools sighted, which might in turn lead to biases in estimates of Antarctic minke whale numbers and their trends over time.

MATERIALS AND METHODS

Data from the IWC/IDCR-SOWER surveys from 1993/94 to 1998/99 are used, which constitute part of the third circumpolar set of surveys (there is no record of which observer made a particular sighting before 1993/94). The data on the experience of the primary observers were extracted from Matsuoka *et al.* (2001), and other data were extracted from the database package DESS (IWC Database-Estimation System Software v3.1, Strindberg and Burt, 2000). All these surveys were carried out by two vessels: the *Shonan Maru* and *Shonan Maru No. 2* (SM and SM2 respectively). From 1993/94 until 1997/98 there were five topmen observers on each vessel; in 1998/99 there were six topmen observers on the SM and seven topmen observers on the SM2.

Survey effort is divided into closing mode and passing mode with an independent observer (IO mode). In IO mode, two topmen (primary observers) observe from the barrel and a third topman (primary observer) is stationed in the independent observer platform (IOP). Additionally, on the upper bridge, there are two primary observers (the Captain

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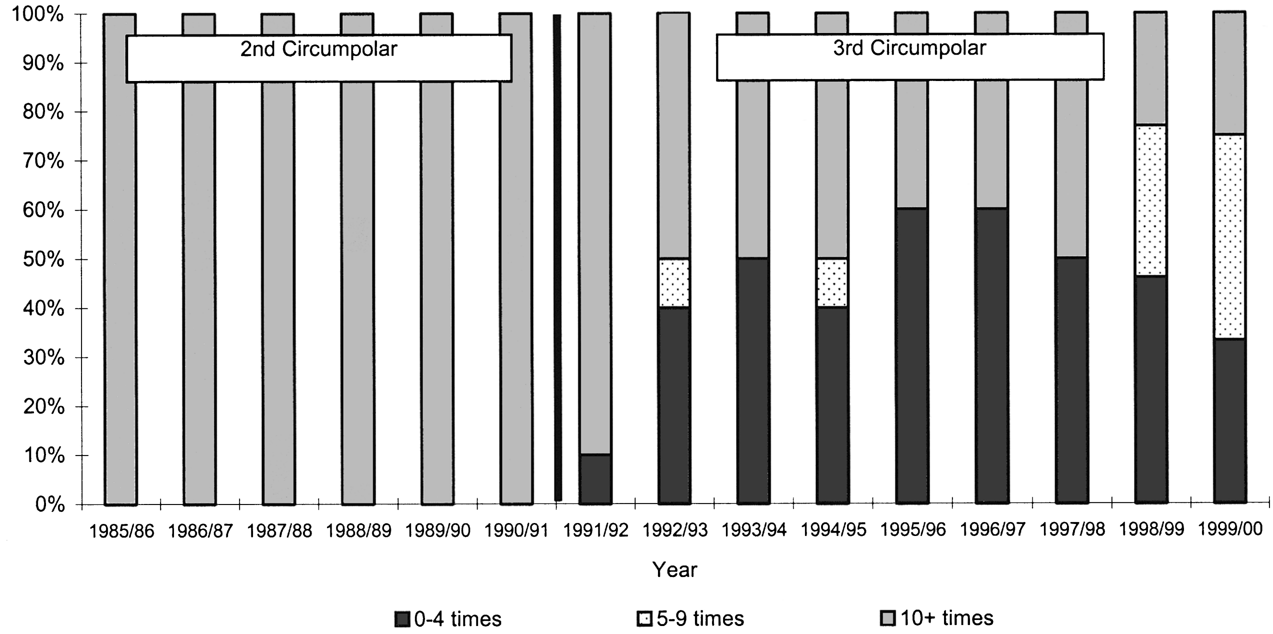


Fig. 1. Survey experience of the primary observers (including Captains) on the IWC/IDCR and SOWER surveys (Japanese vessels only). (Reproduced from Matsuoka *et al.*, 2001).

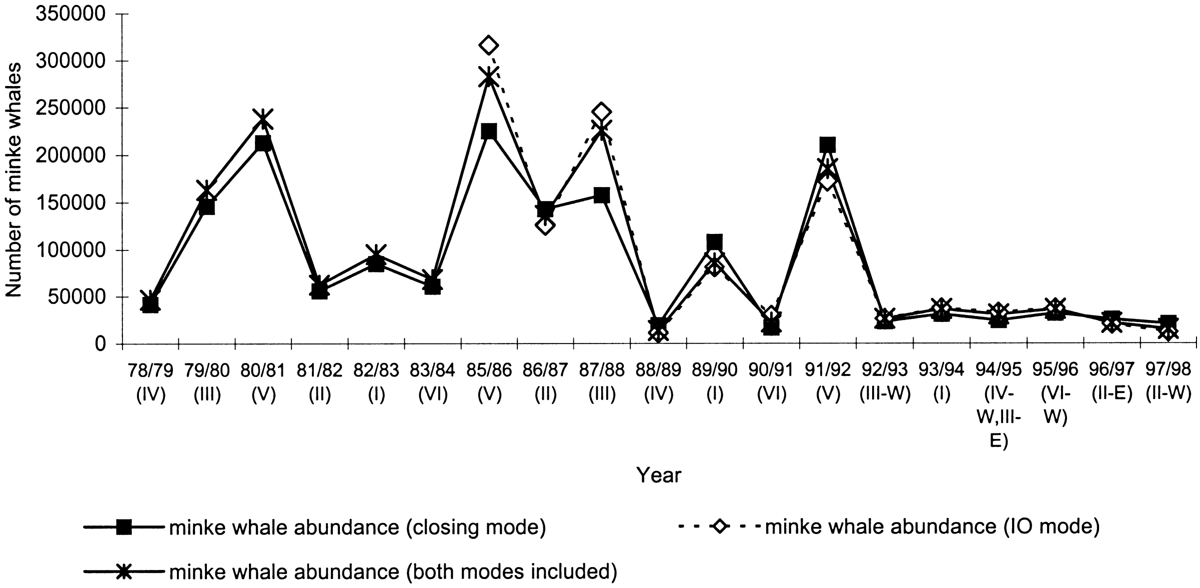


Fig. 2. Estimated minke whale abundances (source: Branch and Butterworth, 2001, table 6, which adjusts the basic surveys estimates to correspond to comparable longitudinal and latitudinal coverage over the three circumpolar sets of surveys).

and helmsman), accompanied by an engineer and three researchers who also observe. The barrel is located at a height of 20m above sea level, and the IOP is located below the barrel, 14m above sea level. The upper bridge is located below the IOP and is 11m above sea level (Matsuoka *et al.*, 2001). Prior to the 1998/99 cruise the IOP (as well as the upper bridge platform) of the SM was extensively modified. The height above sea level of the IOP and the number of observers was not changed; however the modifications greatly improved the wind protection and may have had an effect on sightability from both of these platforms. The barrel was not modified.

In closing mode, the vessels divert to close on virtually every sighting made, whereas in IO mode no such diversions from the trackline take place. In IO mode, no information is exchanged between the barrel and the IOP, nor is either of these platforms informed of sightings made from the upper bridge (Matsuoka *et al.*, 2001). This paper analyses the relationship between the experience of the topman observer and the number of minke whale schools sighted from the barrel and the IOP. (Hereafter, 'observer' refers to a topman observer acting as a primary observer in the barrel or IOP.)

Species code and activity code

The species code for minke whales is '04' for the 1993/94 to 1996/97 cruises. For the 1997/98 and 1998/99 cruises, species codes for minke whales are '04' (minke whale) and '91' (undetermined minke whale; the observer is sure it is a minke whale but not whether it is the Antarctic or dwarf form). The species code for like-minke whales is '39' for all cruises. The species code '39' as used during the 1997/98 and 1998/99 cruises had a different meaning, but estimates in DESS were subsequently modified to achieve consistent meaning over time following recommendations in Branch and Ensor (2001). It should be pointed out that the observers in the barrel and IOP although having detected a sighting, do not necessarily decide on the species identification. During IO mode, a proportion of the identifications are made by the upper bridge observers (for example, the barrel and/or IOP may classify a sighting as 'like minke' but the upper bridge observers, while attempting to track the sighting, may resight it and be able to identify it as 'minke').

The activity code for IO mode survey is 'BO' (Strindberg and Burt, 2000). The analysis was restricted to IO mode and sightings from the barrel and the IOP only, to avoid the complications of including sightings from the upper bridge where the total numbers of observers can vary, and of potential barrel sightings in closing mode that can be 'lost' because they are seen first from other platforms.

Classification of observers

A total of 46 observers participated in the IWC/IDCR-SOWER surveys from 1993/94 to 1998/99. Experience varied from 0-20 previous participations, where this count includes experience in the North Pacific sighting surveys. In order to find the best categorisation of the observers by experience, two different analyses using generalised linear models (GLMs) were conducted (McCullagh and Nelder, 1989), as shown in equations (1) and (2). S-plus software (Math Soft. Inc., 2000) was used for the calculations.

$$E(n_O) = \exp(\log(L_{IO}) + \mu + \alpha_{Exp.no} + \beta_{Vessel} + \delta_{Year}) \quad (1)$$

$$E(n_O) = \exp(\log(L_{IO}) + \mu + \alpha_{Exp.cat} + \beta_{Vessel} + \delta_{Year}) \quad (2)$$

where:

- n_o is the number of minke whale schools sighted per individual observer O, per vessel, per survey from the IO platform, and is assumed to have an over-dispersed Poisson distribution;
- L_{IO} is an offset denoting number of minutes that observer O observed from the IO platform;
- μ is the intercept term;
- $\alpha_{Exp.no}$ is a factor related to observer O's experience in terms of number of previous sighting surveys;
- $\alpha_{Exp.cat}$ is a factor related to various groupings of observer experience;
- β_{Vessel} is a vessel effect (SM or SM2); and
- δ_{Year} is a year effect (1993/94 to 1998/99).

Equation (1) represents the most general model reported here for which the observer experience is ungrouped. Some investigations including interaction terms did not result in any change to the level of grouping ultimately chosen, so that incorporation of such terms was not pursued further for this purpose. The expressions $\alpha_{Exp.no}$, β_{Vessel}, δ_{Year} and $\alpha_{Exp.cat}$ were treated as categorical variables. Only sightings data from the IO platform were used because there might be some interaction between the two observers in the barrel. For $\alpha_{Exp.cat}$ in equation (2), various groupings of observer experience were considered and stepwise model selection based on Akaike's Information Criterion (AIC; Akaike, 1973) was used to select the most appropriate grouping:

$$\text{AIC} = -2\log\left(L\left(\theta|x\right)\right) + 2K \quad (3)$$

where:

- $L(\theta|x)$ is the likelihood function of the model parameters, given the data x; and
- K is the number of estimable parameters.

If the sampling variance exceeds that expected for a Poisson model ($\text{Var}(n) = E(n)$), AIC is modified based on principles of quasi-likelihood, and model selection is based on QAIC (Burnham and Anderson, 1998), which is defined as:

$$\text{QAIC} = \left[\frac{-2\log\left(\text{L}\left(\theta|x\right)\right)}{\hat{c}}\right] + 2K \quad (4)$$

where:

- $\hat{c}$ is the over-dispersion parameter estimated from the goodness-of-fit chi-square statistic (χ^2) of the global model and its degrees of freedom (df), $\hat{c} = \chi^2/df$.

Comparison among individual observers

Sighting rate

GLM was used to investigate the variation in the number of minke whale schools sighted. For covariates, we used the proportion of searching time spent in the IOP, observer experience group, year, vessel and some interaction terms between these variables were used. The expected number of minke whale schools sighted by observer group O is first modelled as:

$$E(n_O) = (L_{BO} + L_{IO})\exp(\mu + \theta R_O + \alpha_{Exp} + \beta_{Vessel} + \delta_{Year} + R_O * \alpha_{Exp} + \beta_{Vessel} * \alpha_{Exp} + \delta_{Year} * \alpha_{Exp}) \quad (5)$$

where:

n_O, L_{BO}, L_{IO}, μ, β_{Vessel}, and δ_{Year} have the same meaning above, as for equations (1) and (2) above;

- R_O is the fraction of time spent in the IO platform by the observer i.e. $L_{IO}/(L_{IO} + L_{BO})$, with θ the associated parameter (this allows for the possibility that sighting efficiency differs between the barrel and the IOP);
- α_{Esp} is the category denoting the observer's experience (for Beginner or Expert – the two categories are determined and defined in the Results section following); and

$R_O * \alpha_{Exp}$, $\beta_{Vessel} * \alpha_{Exp}$, $\delta_{Year} * \alpha_{Exp}$ indicate interaction terms.

α_{Exp}, β_{Vessel} and δ_{Year} were treated as categorical variables.

Perpendicular distance difference

For abundance estimation, not only the number of schools sighted, but also the effective search half-width (w) for schools is an important quantity. Possible differences in the perpendicular distance distributions among the observer groups were investigated to check whether this might help explain observed changes in sighting rate. The log transformed perpendicular distance (y in n.miles) was modelled for each observation as follows:

$$\ln(y + 0.1) = \mu + \alpha_{Exp} + \phi_{Sight} + \gamma_{lat} + \beta_{Vessel} + \delta_{Year} + s\eta + \varepsilon \quad (6)$$

where:

μ, α_{Exp}, β_{Vessel}, and δ_{Year} have the same meaning as above;

- ϕ_{Sight} is the effect of sightability – a code from 1-5 recorded to reflect a general impression of how good conditions are for spotting whales;
- γ_{lat} is the effect of latitude (Northern stratum and Southern stratum);
- s is the best school size estimate (whether or not this estimate was confirmed) with η the associated parameter; and

ε is an error term (the transformation used was found to lead to a distribution for ε which was approximately normal and homoscedastic).

α_{Exp}, ϕ_{Sight}, γ_{lat}, β_{Vessel} and δ_{Year} were treated as categorical variables.

Radial distance difference

To see whether Experts tend to sight minke whales further away than the Beginners, radial distance (denoted by r, in n.miles) was modelled as follows:

$$\ln(r+0.1)=\mu+\alpha_{Exp}+\phi_{Sight}+\gamma_{lat}+\beta_{Vessel}+\delta_{Year}+s\eta+\varepsilon \quad (7)$$

The notation is the same as for equation (6). The residuals were again approximately normal and homoscedastic.

Comparison among observer combinations

Upper bridge sightings aside, the actual observations in IO mode are made by a combination of three observers: two in the barrel, and one in the IOP. Abundance estimation depends upon the sightings made by such observer combinations. The difference of the sighting rate among these observer combinations was considered. Each observer is regarded as B (Beginner) or E (Expert) in terms of the groupings defined in the Results section following. During the cruises from 1993/94 to 1998/99, there were a total of six different observer combinations (U): EEE, EEB, EBE, EBB, BBE and BBB (note that the third letter refers to the observer in the IOP, and further that combination EBE is equivalent to BEE, and so on, so that only the former is indicated and counted). Over-dispersed Poisson GLM's were used to investigate the differences of sighting rates among observer combinations.

The expected number of minke whale schools sighted by observer combination U, one of these six different combinations, per stratum, vessel and survey, is modelled in six ways with different numbers of explanatory variables. Observer combination EEE occurred on SM2 for the 94/95 and 98/99 survey only. Furthermore the observer combination BBB occurred on the SM2 for the 95/96 survey only, and there were no associated sightings. Because of these small sample sizes for some observer combinations, the addition of interaction terms between the variables was not considered.

Model 1:

$$E(n_U)=L_U\exp(\mu+\alpha_{Exp.Com}+\beta_{Vessel}+\gamma_{Lat}+\delta_{Year}+y_{Med}\lambda) \quad (8)$$

Model 2:

$$E(n_U)=L_U\exp(\mu+\alpha_{Exp.Com}+\beta_{Vessel}+\gamma_{Lat}+\delta_{Year}+y_{Med}\lambda) \quad (9)$$

Model 3:

$$E\left(n_U\right)=L_U\exp\left(\mu+\alpha_{Exp.Com}+\beta_{Vessel}+\delta_{Year}\right) \quad (10)$$

Model 4:

$$E\left(n_U\right)=L_U\exp\left(\mu+\alpha_{Exp.Com}\right) \quad (11)$$

Model 5:

$$E(n_U)=L_U\exp(\mu+\alpha_{Exp.Com}+\beta_{Vessel}+\gamma_{Lat}+y_{Med}\lambda) \quad (12)$$

Model 6:

$$E(n_U)=L_U\exp(\mu+\beta_{Vessel}+\gamma_{Lat}) \quad (13)$$

where:

n_U is the number of minke whale schools sighted by observer combination U per stratum, vessel and survey, and is assumed to have an over-dispersed Poisson distribution;

L_U is an offset denoting the minutes for which combination U is observed;

$\alpha_{Exp.Com}$ is the experience effect of the observer combination (EEE, EBE, etc.);

y_{Med} is the median perpendicular distance of sightings by observer combination U (used as a simple surrogate to reflect effective search half-width), with λ the associated parameter.

A regression line was fitted to the data by ranking the observer combinations in a plausible order of net expertise. The triple combination EEE was ranked as 1, EEB as 2, and so on, with the last triple observer combination BBB ranked as 6. The first five models above were then fitted with the observer combination factor replaced by the covariate of ranked observer combinations, i.e. the efficiency of observer combinations is modelled as an exponential in rank as defined above, with *slope* being the parameter reflecting the change in efficiency per unit change in rank.

Effect of including like-minke whale sightings

The ratio of like-minke whale sightings to minke whale sightings has increased in IO mode especially for the third circumpolar set of surveys (Fig. 3). In order to increase sample size, and to see the effect of including like-minke whales, the analysis was repeated including like-minke whale sightings.

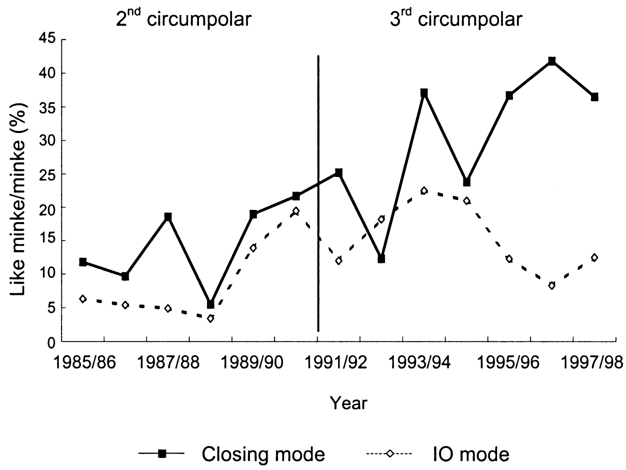


Fig. 3. The percentage increase in the number of minke sightings when like-minkes are included for closing mode and IO mode. The percentages are calculated after smearing and truncation at a perpendicular distance of 1.5 n.miles. (source: Branch and Butterworth, 2001, table 4).

RESULTS

Classification of the observers

Fig. 4 shows the relationship between sighting rate and observer experience from the GLM analysis of equation (1). From this plot, it is evident that the sighting rates for observers who had participated in more than four previous surveys are appreciably higher than for those with less experience. The over-dispersion parameter estimated from the global model of equation (1) is 1.73. Model selection using QAIC was carried out to choose the best basis to divide the observers into groups. The QAIC was the lowest for the model that divided the observer experience into two groups defined by Beginner (0-4 previous surveys), and Expert (> 4 previous surveys) (Table 1). These two groupings were consequently used for the analyses that follow.

Table 1

Results of the GLM analysis for observers grouped on the basis of experience for individual IOP sightings using equation (2). α_{Expert}=0 for each grouping (i.e. this effect is incorporated in the intercept), and the estimates shown are those for the Beginner observers ($\alpha_{Beginner}$).

	Observer experience				
Grouping	Beginner	Expert	Estimate	SE	QAIC
1	0-1	>1	-0.67	0.23	78.66
2	0-2	>2	-0.56	0.19	78.87
3	0-3	>3	-0.62	0.18	72.13
4	0-4	>4	-0.81	0.17	69.5
5	0-5	>5	-0.63	0.16	74.38
6	0-8	>8	-0.58	0.15	75.96
7	0-9	>9	-0.53	0.15	77.54
8	0-10	>10	-0.39	0.15	80.73

An alternative approach to this grouping might have been to fit a monotonically increasing functional form to reflect the effect of experience on sighting rate. However, Fig. 4 suggests that grouping will provide an as good if not better parsimonious representation of any trend in these data as would some smooth functional form.

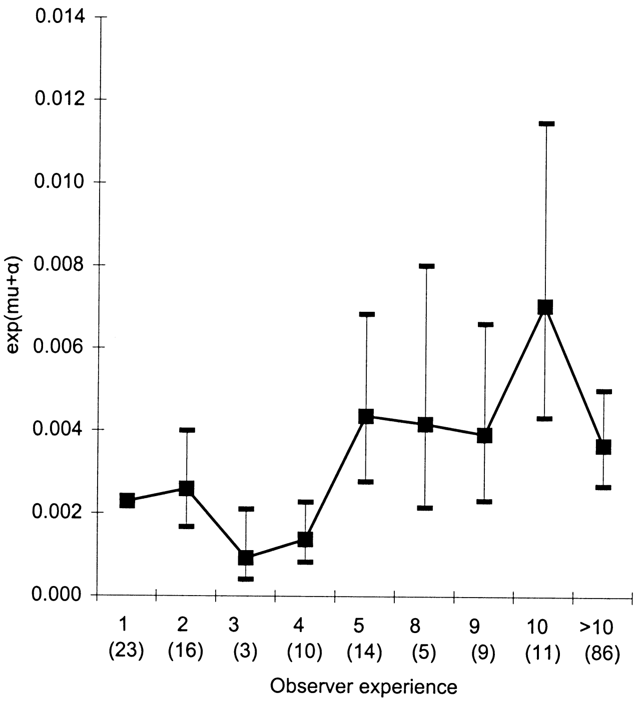


Fig. 4. Sighting rate as a function of observer experience for Individual Observer Platform (IOP) sightings as estimated using equation (1). The intercept is chosen such that $\alpha_1 = \beta_{SM} = \delta_{93/94} = 0$. The bars represent a one standard error range about each estimate, and the numbers shown in brackets are the number of minke whales sighted from the IOP for each observer experience category.

Comparison among individual observers

Sighting rate

The over-dispersion parameter estimated from the model of equation (5), which includes all the covariates, is 2.16. Model selection was carried out using QAIC. The model selected for the number of minke whale schools sighted by observer *O* was given by:

$$E(n_O) = (L_{BO} + L_{IO})\exp(\mu + \alpha_{Exp} + \beta_{Vessel} + \theta R_O + \alpha_{Exp} * \beta_{Vessel}) \quad (14)$$

which had the lowest QAIC of the models considered. The estimated coefficients in relation to the intercept, which incorporates E (Experts) and the vessel SM, are shown in Table 2. The results of the model that excludes the interaction term between the observer experience and vessel are also shown in Table 2 for comparison. When observer experience and vessel interaction effect are excluded, the number of minke whale schools sighted per unit search time (i.e. the sighting rate) by Beginners is significantly lower ($\alpha = 0.05$, df = 44, $p = 0.007$) than that by Experts at a 5% level of significance, by an estimated 42% (95% CI = 22%-56%). However, this difference between Beginner and Experts also differs between vessels. For the observers on the SM, the sighting rate for Beginners is only 16% lower than that for Experts, whereas on the SM2, the sighting rate for Beginners was 57% lower. The minke whale sighting rate by the vessel SM2 is estimated to be 44% or 79% larger than that of SM depending on the model. Fig. 5 shows the sighting rates $N_0/(L_{BO}+L_{IO})$ on vessels SM and SM2 for each individual observer classified as a Beginner or Expert. The sighting rates of the Experts on the SM2 are higher than those on the SM. Occasionally there is a Beginner who has a rather good sighting ability. On the other hand, not all the Experts have high sighting abilities. Motivation and aptitude of the observers is likely also an important factor that influences sighting abilities.

Table 2

Estimates of the coefficient of the model selected (see equation 14) for the number of minke whales sighted by individual observers (from both the barrel and the IOP) are shown in (a). For (b), the vessel-observer experience interaction term is omitted. The intercept is chosen such that α_{Expert}=β_{SM}=0.

Coefficient	Estimate	SE
[a]		
Constant (μ)	-5.45**	0.27
Experience of Beginner ($\alpha_{Beginner}$)	-0.17	0.20
Vessel SM2 (β_{SM2})	0.58**	0.16
R (θ)	-1.83*	0.79
Experience of Beginner:Vessel SM2 ($\alpha_{Beginner}$ * β_{SM2})	-0.68*	0.28
QAIC	69.82	
[b]		
Constant (μ)	-5.32**	0.28
Experience of Beginner ($\alpha_{Beginner}$)	-0.54**	0.15
Vessel SM2 (β_{SM2})	0.37*	0.14
R (θ)	-1.84*	0.82
QAIC	73.37	

*Significantly different from zero at the 5% level. **Significantly different from zero at the 1% level.

The different Beginner:Expert efficiency ratios for the two vessels could be reflecting a number of possibilities, e.g. differences in the actual minke whale densities by longitude for the strata the two vessels surveyed; greater sighting efficiencies of the Experts on the SM2 compared to the SM or weaker abilities of the Beginners on the SM. Fig. 5 is, however, suggestive of support for the central of these three options.

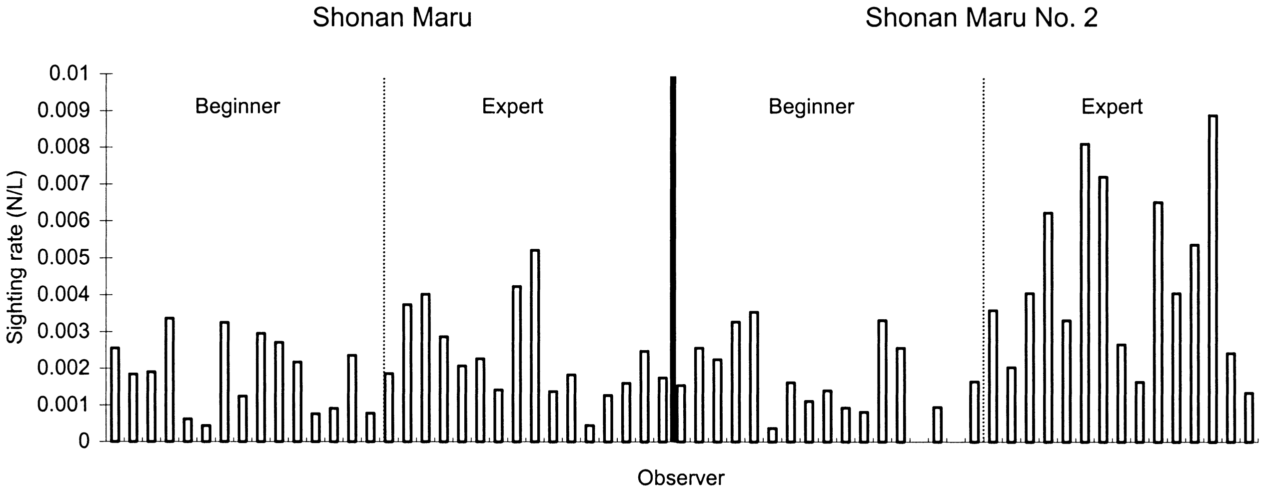


Fig. 5. Sighting rate $N_0/(L_{BO}+L_{IO})$ of minke whale seen from the barrel and IOP for each of the observers on vessel SM and SM2 during the 93/94-98/99 surveys. Observers are categorised as Experts or Beginner depending on whether or not their experience exceeds four cruises.

Perpendicular distance difference
The model selected by AIC is:

$$\ln\left(y+0.1\right)=\mu+\delta_{Year}+s\eta+\varepsilon \quad (15)$$

which includes the effect of year and school size (Table 3). The perpendicular distance of the sighting tends to increase as school size of the sighting increases. Observer experience, however, was not selected and has no significant effect on the perpendicular distances of sightings at the 5% level ($\alpha_{Beginner}=0.026$, $t=0.35$, df = 485, $p=0.73$). This indicates that in this case, consideration of sighting rate alone is sufficient to provide comparable indices of whale density and hence to assess relative observer efficiency.

Table 3

The estimates of the coefficients in the model selected (see equation 15) for the perpendicular distance of minke whale sightings. This model includes the effects of year and best estimate of school size. The intercept is chosen such that $\delta_{93/94}$=0.

Coefficient	Estimate	SE
Intercept (μ)	-1.00**	0.08
94/95 ($\delta_{94/95}$)	-0.02	0.10
95/96 ($\delta_{95/96}$)	0.07	0.12
96/97 ($\delta_{96/97}$)	0.12	0.11
97/98 ($\delta_{97/98}$)	0.24	0.12
98/99 ($\delta_{98/99}$)	0.48**	0.12
School size (η)	0.04**	0.01

**Significantly different from zero at the 1% level.

Radial distance difference
The model selected by AIC is:

$$\ln(r+0.1)=\mu+\phi_{sight}+\gamma_{lat}+\delta_{Year}+s\eta+\varepsilon \quad (16)$$

Again, observer experience was not selected and has no significant effect on the radial distance of the sighting at the 5% level ($\alpha_{Beginner}=-0.06$, $t=-0.76$, df = 485, $p=0.45$). Radial distance tends to increase as school size increases, and tends to be larger for southern compared to northern survey strata (Table 4). These results are not surprising, given that larger school sizes generally produce more cues and that sea conditions and hence sightability are generally better further to the south.

Table 4

The estimates of the coefficients in the model selected (see equation 16) for the radial distance of minke whale sightings. This model includes the effect of sightability, year, school size and latitude. The intercept is chosen such that $\varphi_1=\delta_{93/94}=\gamma_{north}=0$. Sightability 1 refers to 'very poor conditions'.

Coefficient	Estimate	SE
Intercept(μ)	4.13**	0.22
Sightability 2 (poor)	-0.04	0.25
Sightability 3 (moderate)	-0.15	0.19
Sightability 4 (good)	0.08	0.21
Sightability 5 (excellent)	-0.59	0.40
94/95($\delta_{94/95}$)	0.32*	0.12
95/96($\delta_{95/96}$)	0.17	0.15
96/97($\delta_{96/97}$)	0.34*	0.13
97/98($\delta_{97/98}$)	0.33*	0.15
98/99($\delta_{98/99}$)	0.43**	0.14
School size(η)	0.04**	0.01
Latitude South(γ_{south})	0.20*	0.09

*Significantly different from zero at the 5% level. **Significantly different from zero at the 1% level.

Comparison of sighting rate among observer combination
The sighting rate of schools did not show significant differences between observer combinations for any of the models of equations (8)-(13). The estimated differences from the intercept, which incorporates EBE (observer combination), SM (vessel), 93/94 (year) and the northern stratum are shown in Table 5. The analysis above may be compromised because the sample sizes for some observer combinations are very small. To get larger sample sizes for each observer combination so as to attempt greater discrimination power, the observer combinations within the barrel were pooled and a similar analysis was performed. The basis for combining in this way was the assumption that the sighting efficiency of the barrel would be dominated by the experience level of the more experienced of the two topmen. Coefficients for the barrel combination models are shown in Table 6. The sighting rate shows a decrease (see the value of the *slope* parameter) as the experience of the observers decreases for all models that include an observer effect, but in no case is the estimate of *slope* significant at the 5% level. The QAIC criterion suggests that model 6 (which omits any observer effect) is to be preferred among the set proposed.

Table 5

Coefficients from over-dispersed Poisson GLM models fitted to the sighting rate of minke whale schools by observer combinations (observer triplets). Model 1 includes the effects of observer combination, year, vessel, latitude stratum, and median perpendicular distance of the sightings. Model 2 excludes the distance effect from Model 1, and Model 3 excludes both the distance and the stratum effect. Model 4 incorporates only the observer combination effect. Model 5 excludes the year effect from Model 1, while Model 6 has no observer effect. See equations (8) – (13). The intercept is chosen such that $\alpha_{BBB}=\delta_{93/94}=\beta_{SM}=\gamma_{north}=0$. Numbers shown after the observer combinations are the number of minke whales sighted by each observer combination. The parameter 'slope' reflects the change of observer efficiency with combination rank (see text) when observer combination effects are replaced by a linear trend with rank.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Coefficient	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	-6.18**	0.39	-6.07**	0.34	-5.51**	0.30	-5.07**	0.17	-6.06**	0.30	-6.03**	0.12
EEE (28)	0.38	0.43	0.39	0.42	0.33	0.42	0.10	0.42	0.34	0.39		
EEB (33)	-0.40	0.38	-0.39	0.37	-0.38	0.37	-0.40	0.40	-0.42	0.35		
EBE (156)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		
EBB (110)	-0.05	0.25	-0.05	0.25	-0.07	0.25	-0.10	0.26	-0.02	0.23		
BBE (15)	-0.10	0.56	-0.04	0.54	0.12	0.54	-0.04	0.56	-0.04	0.50		
BBB (4)	-0.51	1.01	-0.57	0.99	-0.59	0.98	-0.72	1.05	-0.56	0.93		
94/95	0.28	0.34	0.27	0.33	0.33	0.33						
95/96	0.06	0.38	0.04	0.38	0.08	0.37						
96/97	0.19	0.37	0.18	0.36	0.15	0.36						
97/98	-0.14	0.40	-0.13	0.39	-0.11	0.39						
98/99	-0.22	0.40	-0.14	0.37	-0.06	0.37						
SM2	0.56*	0.22	0.56*	0.22	0.58*	0.22			0.56*	0.21	0.52*	0.22
Lat S	0.99**	0.24	0.97**	0.23					0.97**	0.22	0.96**	0.24
Distance	0.25	0.37							0.08	0.31		
QAIC	77.04		75.48		92.04		89.52		69.56		60.4	
Slope	-0.04	0.13	-0.04	0.13	-0.03	0.11	-0.02	0.11	-0.02	0.11	-	
QAIC	64.33		62.81		76.99		72.44		56.68		52.83	

*Significantly different from zero at the 5% level. **Significantly different from zero at the 1% level.

Table 6

This Table is the same as Table 5 except that observer combinations are now pooled across the observers in the barrel.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Coefficient	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	-6.15**	0.43	-6.03**	0.37	-5.48**	0.31	-5.06**	0.15	-5.98**	0.31	-6.03**	0.24
E*E (184)	0.00		0.00		0.00		0.00		0.00			
E*B (143)	-0.20	0.24	-0.19	0.24	-0.20	0.23	-0.19	0.23	-0.17	0.22		
BBE (15)	-0.15	0.61	-0.09	0.60	0.08	0.56	-0.06	0.56	-0.09	0.53		
BBB (4)	-0.54	1.11	-0.61	1.09	-0.62	1.02	-0.73	1.05	-0.61	1.00		
94/95	0.34	0.36	0.33	0.36	0.38	0.34						
95/96	0.13	0.42	0.10	0.41	0.14	0.38						
96/97	0.24	0.40	0.24	0.39	0.21	0.37						
97/98	-0.07	0.43	-0.07	0.43	-0.06	0.41						
98/99	-0.17	0.43	-0.08	0.40	-0.01	0.38						
SM2	0.52*	0.24	0.51*	0.24	0.54*	0.22			0.52*	0.22	0.52*	0.22
Lat S	0.97**	0.26	0.96**	0.26					0.96**	0.24	0.96**	0.24
Distance	0.27	0.40							0.09	0.33		
QAIC	65.76		64.18		77.21		72.59		58.02		50.91	
Slope	-0.16	0.19	-0.16	0.19	-0.14	0.18	-0.16	0.17	-0.14	0.17	-	
QAIC	63.04		61.55		75.3		70.69		55.41		52.16	

*Significantly different from zero at the 5% level. **Significantly different from zero at the 1% level.

Effect of including like-minke whales

The results for the observer group analysis using equation (14) both with and without the interaction between observer experience and vessel are given in Table 7. When the interaction term is excluded, the sighting rate for Beginners is estimated to be 41% (95% CI = 24%-55%) lower than that of the Experts, which hardly differs from the estimate for minke whale sightings alone. This may reflect the fact that the upper bridge observers make most of the species identifications. The relation between the sighting rates for Beginners and Experts also differed between vessels. For the observers in SM, the sighting rate for Beginners is 25% lower than that for Experts, whereas on the SM2, the sighting rate for Beginners was 52% lower.

Results for the observer combination analysis using equations (8)-(13) are shown in Tables 8 and 9. When like-minke sightings are included, the sighting rate tends to decrease more rapidly as observer experience drops than is the case when only minke whale sightings are considered (see Fig. 6 which shows these results for model 5). The variance of this *slope* estimate declines, probably because of the increased sample size as a result of including like-minke sightings. In terms of the QAIC criteria, a model with an observer effect (model 5) is selected when both like-minke sightings are included and data are pooled across observer combinations in the barrel (Table 9), although even in this case the estimate of *slope* remains not significantly different from zero at the 5% level.

Table 7

Estimates for the coefficients of equation (14) for the number of minke and now also like minke whales sighted by individual observers. Notation is as for Table 2.

Coefficient	Estimate	SE
[a]		
Constant (μ)	-5.27**	0.25
Experience of Beginner ($\alpha_{Beginner}$)	-0.29	0.18
Vessel SM2 (β_{SM2})	0.43**	0.14
R (θ)	-1.13	0.75
Experience of Beginner: Vessel SM2 ($\alpha_{Beginner}$*β_{SM2})	-0.44	0.25
QAIC	66.17	
[b]		
Constant (μ)	-5.18**	0.25
Experience of Beginner ($\alpha_{Beginner}$)	-0.53**	0.13
Vessel SM2 (β_{SM2})	0.29*	0.12
R(θ)	-1.14	0.76
QAIC	66.99	

*Significantly different from zero at the 5% level. **Significantly different from zero at the 1% level.

DISCUSSION

Why do we struggle to detect differences in sighting rates between observer combinations, when there appear to be clear differences for observers individually?

Hypothesis 1. Small sample size for some of the observer combinations

To compensate for the weaker sighting ability of the Beginners (especially those who had not previously participated in a survey), there was an informal rule that observers who had no past experience should be placed in the barrel only together with an Expert. Because of this rule, and the fact that 40-60% of the observers were Beginners (Fig. 1), the observer combination of EB occurs more frequently and searches longer than the combination of EE for the barrel (Table 10). The relatively small proportion of observation time for the EE combination could be one of the reasons for struggling to detect differences between the observer combinations, especially between EE and EB in the barrel.

Table 8

Coefficients from over-dispersed Poisson GLM models fitted to sighting rate of minke whale and now also like-minke whale schools by observer combinations (triple observers). Notation is as for Table 5.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Coefficient	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	-5.86**	0.36	-5.54**	0.32	-4.97**	0.29	-4.64**	0.15	-5.80**	0.30	-5.58**	0.23
EEE (41)	0.27	0.38	0.27	0.40	0.21	0.41	0.05	0.40	0.21	0.35		
EEB (47)	-0.52	0.34	-0.48	0.35	-0.47	0.37	-0.48	0.37	-0.53	0.32		
EBE (239)	0.00		0.00		0.00		0.00					
EBB (152)	-0.15	0.23	-0.16	0.24	-0.18	0.24	-0.20	0.24	-0.11	0.21		
BBE (19)	-0.33	0.52	-0.29	0.54	-0.12	0.56	-0.23	0.56	-0.27	0.48		
BBB (6)	-0.40	0.89	-0.61	0.92	-0.64	0.95	-0.74	0.97	-0.41	0.84		
94/95	0.13	0.31	0.13	0.32	0.18	0.33						
95/96	0.04	0.34	0.05	0.35	0.09	0.37						
96/97	0.17	0.33	0.22	0.34	0.20	0.35						
97/98	-0.19	0.36	-0.17	0.37	-0.15	0.39						
98/99	-0.16	0.34	0.00	0.34	0.08	0.35						
SM2	0.51*	0.21	0.40*	0.21	0.43*	0.21			0.49*	0.20	0.37	0.21
Lat S	0.94**	0.21	0.98**	0.22					0.94**	0.20	0.97**	0.23
Distance	0.64	0.34							0.56	0.30		
QAIC	81.17		82.61		104.71		99.08		73.04		67.90	
Slope	-0.05	0.11	-0.06	0.11	-0.05	0.11	-0.05	0.10	-0.03	0.10	-	
QAIC	70.9		71.71		90.95		84.54		62.48		61.24	

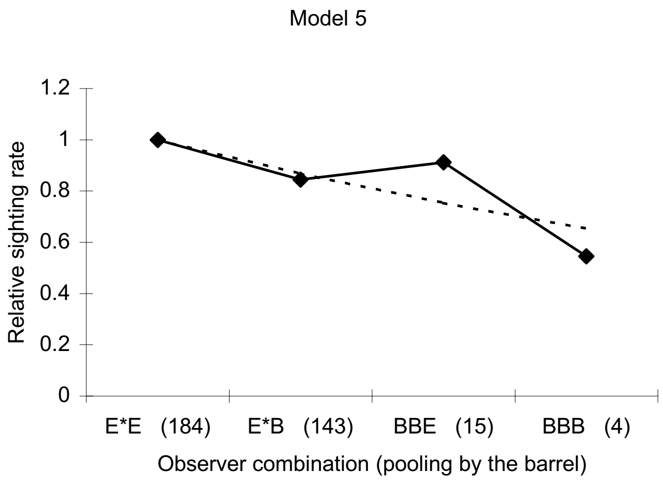
*Significantly different from zero at the 5% level. **Significantly different from zero at the 1% level.

Table 9

Coefficients from over-dispersed Poisson GLM models fitted to sighting rate of minke whale and now also like-minke whale schools by the observer units. Observer combinations are pooled across the observers in the barrel as explained in the text. Notation is as for Table 6.

	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6	
Coefficient	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Intercept	-5.81**	0.38	-5.51**	0.33	-4.96**	0.29	-4.64**	0.14	-5.72**	0.29	-5.58**	0.23
E*E (280)	0.00		0.00		0.00		0.00		0.00			
E*B (199)	-0.29	0.21	-0.28	0.22	-0.29	0.22	-0.28	0.22	-0.26	0.20		
BBE (19)	-0.37	0.55	-0.33	0.57	-0.16	0.57	-0.24	0.56	-0.30	0.50		
BBB (6)	-0.44	0.94	-0.65	0.97	-0.67	0.96	-0.75	0.96	-0.46	0.88		
94/95	0.18	0.32	0.17	0.33	0.22	0.33						
95/96	0.09	0.35	0.10	0.37	0.13	0.37						
96/97	0.23	0.34	0.26	0.35	0.24	0.35						
97/98	-0.13	0.38	-0.12	0.39	-0.11	0.39						
98/99	-0.12	0.35	0.03	0.35	0.10	0.34						
SM2	0.47*	0.21	0.37	0.21	0.40	0.21			0.45*	0.20	0.37	0.21
Lat S	0.92**	0.23	0.97**	0.23					0.92**	0.21	0.97**	0.23
Distance	0.61	0.36							0.52	0.31		
QAIC	72.76		73.57		92.7		86.09		64.57		61.09	
Slope	-0.23	0.17	-0.24	0.17	-0.22	0.17	-0.23	0.17	-0.21	0.15	-	
QAIC	69.28		70.07		89.61		82.88		61.07		61.46	

*Significantly different from zero at the 5% level. **Significantly different from zero at the 1% level.



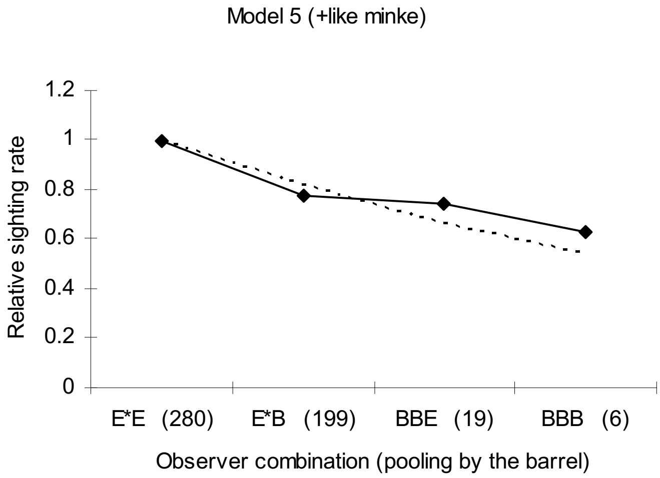


Fig. 6. Comparison of relative sighting rate ($\exp(\mu+\alpha_{E*E}) = 1$) for the observer combination pooled by the barrel for Model 5 (equation 12). The top figure shows results for minke whale sightings, and the bottom are for minke whale and like-minke sightings. The dotted line shows the regression with observer combinations ranked to yield an estimate of slope. Model 5 includes the effect of the observer combination, vessel, latitude and median perpendicular distance of the sightings. The model's intercept incorporates $\alpha_{E*E} = \beta_{SM} = \gamma_{north}$ Numbers shown in brackets are the number of whales sighted by each observer combinations (* designates either or E or B).

Table 10

Percentage of searching time for each observer group (pooled over the IOP) (*designates either of E or B).

Year	Vessel	EE*	EB*	BB*
93/94	SM1	7.2	65.8	27.1
	SM2	25.7	74.3	0
94/95	SM1	27.5	72.5	0
	SM2	24.7	75.3	0
95/96	SM1	0	98.6	1.4
	SM2	6.4	64.2	29.5
96/97	SM1	12	75.8	12.2
	SM2	3.5	96.5	0
97/98	SM1	41.3	55.1	3.6
	SM2	3.8	96.2	0
98/99	SM1	51.1	48.9	0
	SM2	34.1	65.9	0
Average over all years	SM1	23.2	69.5	7.4
	SM2	16.4	78.7	4.9
	SM1+SM2	19.8	74.1	6.2

Hypothesis 2. A compensating effect for the EB combination with the Expert observer also 'stealing' observations that the Beginner would have made later if on his own

Another possible explanation for the lack of significant differences (at the 5% level) between the efficiencies of triple observer combinations might be that, for example, Experts are dominating the sightings process when the EB combination is in the barrel. The ratio of sightings of minke whale schools by the two groups of observers when the EB combination is present in the barrel is shown in Fig. 7. 70% of the minke whale schools are seen by the Experts. This hypothesis suggests also that the analysis that results in Table 2, which incorporates barrel sightings, would lead to negatively biased estimates of the efficiency of Beginners. However, Table 1 for observers on their own in the IOP gives results very similar to Table 2b. The sighting rate of the Beginners is significantly lower, by an estimated 52% (95% CI = 27%-68%) than that of the Experts in the IOP. This argues against any 'stealing' effect in the barrel sightings, and it is difficult to conceive that there could be a major compensating effect by Experts in the absence of any such 'stealing' (i.e. that possible 'extra' sightings made by an Expert in combination with a Beginner are nearly all ones the Beginner would not have made). This detracts from the likelihood that this hypothesis is the primary explanation for the difficulty in detecting significant differences in sighting rate with combined observer experience for the triple combinations of observers in the barrel and IOP in IO mode survey.

Thus on balance, it is suspected that the struggle to detect differences in sighting rates for the observer-combinations is more likely a consequence of small sample size for the EEE combination (which was dominant in all the cruises of the second circumpolar set of surveys) than of Expert observers compensating for and/or 'stealing' sightings from less experienced companions in the barrel.

Influence on abundance estimation

The estimated abundance of minke whales has decreased by some 50% between the second circumpolar set of surveys and the third, according to the analysis of Branch and Butterworth (2001). It seems reasonable to postulate that the introduction of Beginner observers during the third set may be responsible for part of this decrease. This is particularly because from the initial analysis of individual observers, which showed no differences in perpendicular distances of sightings between Beginners and Experts, the sighting rate by Beginners is estimated to be 43% (95% CI: 14%-73%) less than that by Experts. Moreover, when like-minke whale sightings were included, the trend of sighting rate with decreased observer experience, particularly after pooling over observer combinations in the barrel, shows a negative trend (though admittedly not statistically significant at the 5% level). This suggests that the probability that a school on the trackline will be sighted, $g(0)$, for the Beginners is smaller than the $g(0)$ for the Experts during IO mode survey. This contrasts with the assumption made for previous abundance estimation from the observations on these surveys (e.g. Branch and Butterworth, 2001) that $g(0) = 1$ irrespective of year, area, vessel, observers, or weather conditions. Supporting evidence for the possibility of a decrease in $g(0)$ for more recent surveys is provided by the fact that the proportion of sightings from the barrel and the IOP in IO mode that are classified as definite duplicates has

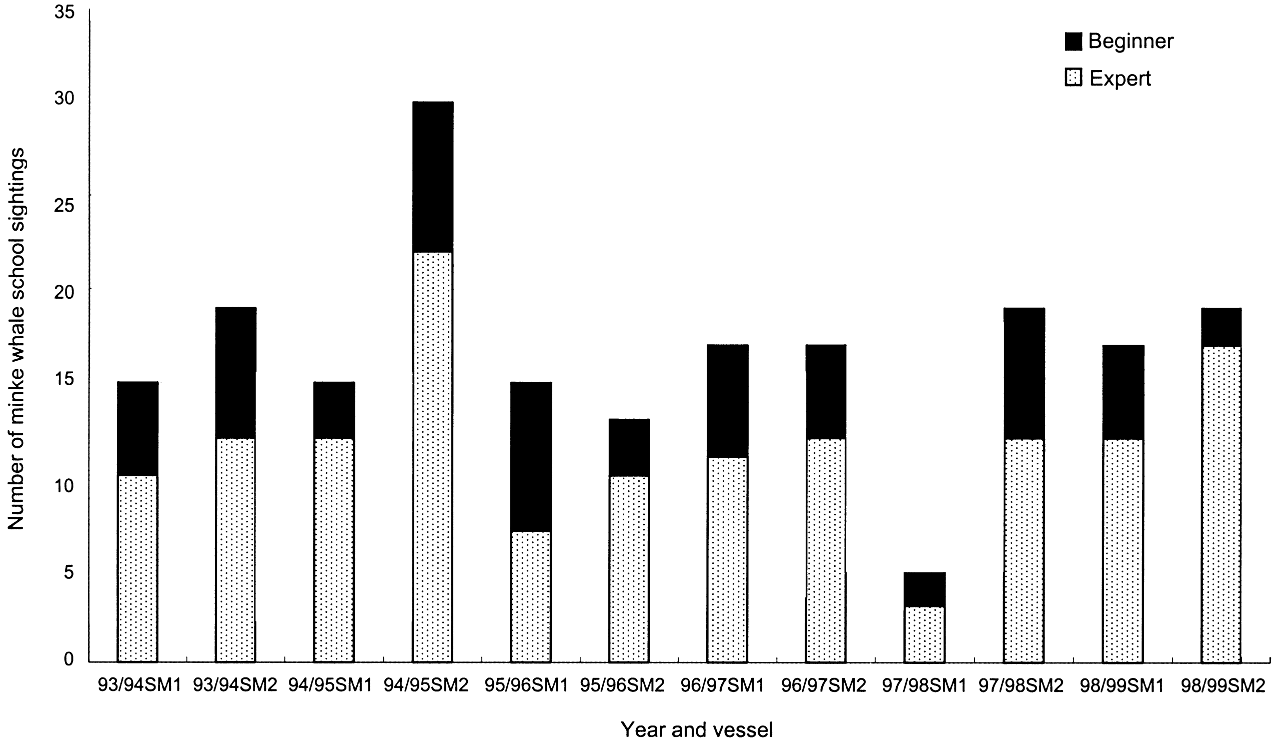


Fig. 7. Number of minke whale schools sighted by B (Beginner) and E (Expert) observers when B and E are together in the barrel in IO mode survey.

decreased by 40% for Area I (Okamura *et al.*, 2002), 15% for Area II and 43% for Area VI between the second and the third sets of circumpolar surveys (Mori *et al.*, 2002).

Possible sighting experiment

One possibility to examine whether the low proportion of observing time with the EE combination in the barrel reduced the chance of detecting a significant difference among observer combinations would be to conduct an experiment. This would involve alternating EE and EB combinations in the barrel on a regular basis to achieve a balanced statistical design and so enhance the probability of detecting differences. Introducing this kind of experiment and collecting sighting data for several years may yield an improved basis to estimate the relative sighting abilities of the EE and EB combinations in the barrel. This may provide a basis for making quantitative adjustments for likely underestimation of minke whale abundance because of the presence of Beginner observers.

Training of the beginners

There is no evaluation system for the sighting ability of the observers. Most of the new observers are recruited in April (and a few join slightly later), and they participate in a two-month sighting survey from June to August. They then participate in the IWC/IDCR-SOWER survey, which normally departs from Japan in November. At the beginning of each IWC/IDCR-SOWER survey cruise, for about three weeks (from Japan to the homeport for the survey), observers practise making sightings (Matsuoka, pers. comm.). However, the area where this takes place is generally one in which the sighting rate for minke whales is very low (Ensor, pers. comm.) so that this still leaves considerable room for the possibility that the sighting abilities of the Beginners remain lower than those of the Experts.

Sighting surveys cost a considerable amount of money and time. It is not easy to create opportunities for Beginners to practice on board in advance. For this reason, all cruises since 1998/99 have had additional topmen on board for training. Virtual training to find whales using videos from the IWC/IDCR-SOWER surveys may also help Beginners to improve their sighting ability. Some new observers retire from sighting surveys after only one year. Continuous participation in sighting surveys should be encouraged for the improvement of sighting ability.

Importantly, changes in observers' sighting ability between circumpolar sets of surveys may bias estimates of population trends. For the IWC/IDCR-SOWER surveys, there have been frequent changes in the survey methods, including the number of vessels used, extents of areas covered, and survey starting dates and modes. Consistent methods need to be encouraged for long-term surveys. Before any survey method is modified, there is a need to establish how to transform the estimate obtained from the previous method to that from the improved method. There also needs to be an education or internship system to improve the sighting ability of the observers, as for Hawk Mountain's raptor monitoring (Bildstein *et al.*, 2000).

Briefing before and after the sighting survey is important and observers need to be motivated about the importance of their work. Communication among observers and scientists must also be encouraged.

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